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Osmotic dehydration of tomato in ternary solutions: Influence of process variables on mass transfer kinetics and an evaluation of the retention of carotenoids

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Abstract

The objective of this work was to study the influence of temperature (20–40 °C), solution composition (0%salt/65%sucrose–10%salt/55%sucrose) and agitation speed (0–1000 rpm) on the mass transfer kinetics of osmotically dehydrated tomato halves. The mass transfer kinetics were modeled using a first-order kinetic equation, by way of an empirical parameter (k) representing an overall mass transfer coefficient. Carotenoid retention was analyzed after 6 h of processing. The results showed that the overall mass transfer coefficients for water, NaCl and sucrose were positively influenced by the temperature and by an increasing solution salt content. The agitation speed had a significant influence on water loss, indicating that in this case, the mass transfer was not only governed by an internal mechanism, as appeared to be the case with the solutes. Osmotic dehydration apparently had no effect on the carotenoid content of the processed products, and can be considered to be an efficient method, allowing for water removal without changing the nutritive value.
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Keywords: Osmotic dehydration; Tomato; Mass transfer; Sucrose; Sodium chloride; Agitation speed; Carotenoids

1. Introduction

The tomato is one of the most consumed fruits in the world. It is found fresh or dried in salads, as well as in various industrialized products, such as sauces, juices and ketchup. The ingestion of tomato has been related to the prevention of some types of cancer, due to its lycopene content. Lycopene is the most abundant carotenoid in tomatoes and is considered to be an important nutrient, since it shows high antioxidant activity (Shi, Le Maguer, Kakuda, Liptay, & Niekamp, 1999).

The consumption of dried tomato has increased and become very popular. This product can easily be found in many restaurant menus, as an ingredient of various dishes. In Brazil, dried tomato is generally manufactured by small producers, who keep their production method secret. However, for large-scale industrial production, it is important to develop a high quality product, in an economically viable way. Drying is usually a long process that requires high temperatures, leading to degradation and oxidation of some nutrients.

Osmotic dehydration (OD) can be considered as an important step prior to drying, since it provides a reduction in nutrient losses and an improvement in product quality (Mandala, Anagnostaras, & Oikonomou, 2005; Riva, Campolongo, Leva, Maestrelli, & Torreggiani, 2005), besides promoting energy saving (Lenart, 1996; Raoult-Wack, 1994). In such processes, the product is soaked in a hypertonic solution, where two main countercurrent mass transfer flows take place: a water flow from the product to the solution and a solute migration from the solution to the product. Leaching of the product's own solutes is

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Nomenclature

β	regression coefficients of Eq. (8)	*suc*	sucrose content (g)
ρ	solution density (kg/m^3)	*WR*	weight reduction (%)
μ	solution viscosity (kg/m s)	*x*	coded independent variable of Eq. (8)
θ	time (s)	*X*	moisture content (wet basis)
D	impeller diameter (m)	*y*	dependent variable of Eq. (8)
ICC	increase in carotenoid content (%)		
k	overall mass transfer coefficients (s$^{-0.5}$)	*Subscripts*	
m	sample mass (g)	0	initial
N	impeller revolution speed (rev/s)	1	temperature
NMC	normalized moisture content	2	solution composition
NSaltC	normalized salt content	3	agitation
NSucC	normalized sucrose content	f	final
R^2	determination coefficients	salt	salt
Re	Reynolds number	suc	sucrose
salt	salt content (g)	w	water

quantitatively negligible, but can be important with respect to the sensory and nutritional product characteristics.

OD processes generally involve the use of concentrated solutions, which, consequently, have relatively high viscosities. Viscosity is an important physical property, since it has a great influence on the agitation level required by the process, representing an important economical aspect that must be considered. In addition, when the osmotic medium is highly viscous, mass transfer can become more difficult and, in this case, the assumption that external resistance to mass transfer is negligible (as in the case of most models that describe OD kinetics), cannot be made (Chenlo, Moreira, Pereira, & Ampudia, 2002; Lazarides, Katsanidis, & Nickolaidis, 1995).

The influence of agitation speed on osmotic processes has not been widely studied in the literature. Moreira and Sereno (2003), when studying the osmotic dehydration of apple cylinders under static and non-static conditions, verified that the dehydration rates increased with increasing solution flow rates. In addition, the samples tended to show lower equilibrium moisture contents, when compared to the processes performed under static conditions. On the other hand, the gain in solids was not affected by agitation. Panagiotou, Karathanos, and Maroulis (1999) observed the opposite behavior, working with apple, banana and kiwi. The authors verified that the sucrose mass transfer was a function of agitation speed, while water mass transfer was independent of this variable.

The two most widely used solutes for osmotic treatments are sugars and salts, mainly sucrose and sodium chloride (Giraldo, Talens, Fito, & Chiralt, 2003; Mayor, Moreira, Chenlo, & Sereno, 2006; Park, Bin, Brod, & Park, 2002; Telis, Murari, & Yamashita, 2004). Some authors have reported the use of ternary solutions (mixtures of sugars and salts) as an advantageous method, leading to higher water losses with lower solids gains and also providing an increase in the total solution concentration, without reaching the saturation limits (Bohuon, Collignan, Rios, & Raoult-Wack, 1998; Medina-Vivanco, Sobral, & Hubinger, 2002; Qi, Le Maguer, & Sharma, 1998).

The aim of this work was to study the influence of agitation speed, solution composition and process temperature on the overall mass transfer coefficients for water and solutes, during the osmotic dehydration of tomato halves in ternary solutions of water/sucrose/NaCl, at a fixed total solids concentration of 65% (w/w). Carotenoid retention was also evaluated, after 6 h of processing.

2. Theory

A diffusional model is generally used to model mass transfer during osmotic dehydration, based on Fick's second law (Lazarides, Gekas, & Mavroudis, 1997; Rastogi & Raghavarao, 2004; Rodrigues, Cunha, & Hubinger, 2003), which considers the external resistance to mass transfer to be negligible as compared to the internal one. Crank (1975) solved Fick's equation, based on a slab semi-infinite approach, and concluded that the mass of diffusing substance varies linearly with the square root of time, when surface concentration is constant.

Based on this observation, Hawkes and Flink (1978) suggested the use of simplified versions of the non-steady state form of Fick's law to model osmotic dehydration kinetics. These authors proposed an empirical model that considered a linear dependence of water loss and solids gain on the square root of residence time. Using this model, it is possible to determine *k*, an empirical parameter that can represent the water and solutes mass transfer coefficients:

$$NMC = 1 - k_{\mathrm{w}} \cdot \theta^{0.5} \quad (1)$$

$$NSaltC = k_{\mathrm{salt}} \cdot \theta^{0.5} \quad (2)$$

$$NSucC = k_{\mathrm{suc}} \cdot \theta^{0.5} \quad (3)$$

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