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ScienceDirect
Journal of Food Engineering 80 (2007) 914–921
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

A membrane-based process for the clarification and the concentration of the cactus pear juice

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Received 31 May 2006; received in revised form 8 August 2006; accepted 9 August 2006
Available online 6 October 2006

Abstract

Cactus pear fruit is a food of nutraceutical and functional importance. Unfortunately, the low acidity and the high soluble solids content make the pulp of this fruit a very attractive media for growth of microorganisms requiring a thermal treatment (115.5 °C or higher) to obtain a good control of the microbial invasion. A relatively long thermal treatment (100 °C for 20 min) can produce a good microbiological stability; however the final product is characterised by an unattractive hay taste and does not resemble the original fresh juice due to changes in colour and flavour.

The aim of this study was to study the potentiality of a membrane-based process for the clarification and the concentration of the cactus pear fruit juice. The fresh juice, with a total soluble solids (TSS) content of about 11 °Brix, was previously clarified by an ultrafiltration (UF) step, on laboratory scale, according to the batch concentration mode. The clarified juice was then concentrated by osmotic distillation (OD) up to a TSS content of 61 °Brix at 28 °C. An initial evaporation flux of 1.16 kg/m^2 h was obtained using a calcium chloride dehydrate solution at 60 w/w% as stripper.

The juice quality was analysed in terms of total antioxidant activity (TAA), ascorbic, citric and glutamic acid, betalains and viscosity in order to evaluate the effects of the membrane processes on the quality and composition of the juice.

Keywords: Cactus pear juice; Ultrafiltration; Osmotic distillation; Betalains; Total antioxidant activity

1. Introduction

Cactus pears (*Opuntia ficus-indica*) originated in tropical America (Russel & Felker, 1987) and can be found in subtropical and tropical areas (Barbera, 1995).

Fruits are fleshy berries, varying in shape, size and colour containing hard seeds. They have a great interest because of their nutritional and antioxidant properties mainly due to the presence of ascorbic acid, fibers and aminoacids (Stintzing, Schieber, & carle, 2001). In particular the level of ascorbic acid can reach values of 40 mg/100 g (Rodriguez, Orphee, Macias, Generoso, & Gomes Garcia, 1996); Mineral salts such as calcium and phosphorous are present at levels of 15.4–32.8 mg/100 g and 12.8–27.6 mg/100 g, respectively. Potassium is another important source of minerals contained at levels of about 217 mg/100 g (Sepúlveda & Sáenz, 1990). Betalains are pigments of cactus fruits with high molar extintion coefficients and with a colouring power competitive to synthetic colorants. They must be preserved during processing since they are responsible for the final attractive colour of the product.

The cactus pear fruit is classified in the low-acid group (pH > 4.5) requiring a thermal treatment of 115.5 °C, or greater, to obtain a good control of microorganisms. The pH, low acidity and high soluble solids content make cactus-pear pulp susceptible to microbial attack, thus limiting its storage life (Joubert, 1993). In this juice, several lengthy thermal treatments (100 °C for 20 min) permit to produce

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doi:10.1016/j.jfoodeng.2006.08.005

Nomenclature

J_w	evaporation flux (kg h^{-1} m^{-2})
T	temperature (°C)
a_w	water activity
x	solute mass fraction (w/w%)
TSS	total soluble solids (°Brix)
Q	flow rate (l/h)
Greek symbols	
ΔP	transmembrane pressure (bar)
Δa_w	water activity difference
μ	dynamic viscosity (Pa s)
Subscripts	
b	brine
j	juice
p	permeate
r	retentate

bottled juice with a good stability; however the final product did not resemble the original fresh juice due to changes in colour and flavour other than an unattractive hay taste (Carrandi, 1995). In order to preserve the juice Espinosa et al. (1973) added lemon juice reducing its pH to 4.0 and then the blend was submitted to a mild thermal treatment (80 °C for 20 min): however the juice preserved in these conditions presented acetic fermentation and the juice could not preserved for a long time.

The increasing market demand for this fruit has lead researchers to develop processed items with increased shelf-life able to retain as much as possible the peculiarity of fresh fruit, as well as colour, aroma, nutritional value and structural characteristics.

Another possibility related to cactus pear juices was concentrated juice production. The lower water activity of the concentrated juice relative to the natural juice is a clear protection against the growth of microorganisms and can extend the shelf-life of the juice. In addition, package, storage and costs are remarkably reduced. Concentrated juices with 63–67 °Brix were obtained by using an Alfa-laval centrifuge vacuum evaporator, at approximately 40 °C. The stability of the juice against microorganisms growth was good, but the sensorial analyses found the acceptability was only 5.0 (1–9 point scale). This unsatisfactory ranking was due to damage to the colour and the herbaceous aroma that appeared after the concentration process (Sáenz, Sepúlveda, Araya, & Calvo, 1993). In addition colour changes were observed during thermal treatment in pasteurised and concentrated juices of green cactus pear. Alternative methods of concentration, such as freeze concentration, require less energy, but they are expensive and limited in the degree of achieved concentration (Köseoglu, Lawhon, & Lusas, 1990).

The basic properties of membrane operations make them ideal in the production of fruit juices with high quality, natural fresh taste and additive-free. They are generally athermal and do not involve phase changes or chemical additives; besides, they are simple in concept and operation and characterised by low energy consumption.

Juice clarification, stabilisation, depectinization and concentration are typical steps where membrane processes as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been successfully utilised (Álvarez, Riera, Álvarez, & Coca, 1998; Gökmen, Borneman, & Nijhuis, 1998; Todisco, Tallarico, & Drioli, 1998). In particular, UF and MF represent a valid alternative to the use of traditional fining agents (gelatine, bentonite and silica sol) and filter aids which cannot be reused and cause pollution problems due to their disposal (Eykamp, 1995). In these processes the juice is separated into a fibrous concentrated pulp and a clarified fraction free of spoilage microorganisms.

Membrane concentration processes such as reverse osmosis (RO), membrane distillation (MD) and osmotic distillation (OD) are able to overcome some of the problems associated with thermal evaporation.

RO has achieved some commercial success in the fruit juice concentration: it presents the advantages of a lower thermal damage to the product, reduction in energy consumption and lower capital equipment costs. However the final concentration of juices is limited to about 25–30 °Brix due to the high osmotic pressure of the feed at those levels. So it could be employed as a preliminary step in a two-stage concentration (Barbe, Bartley, Jacobs, & Johnson, 1998).

MD, in comparison with pressure-driven membrane processes, permits to reach higher concentrations of dissolved solids (60–65 °Brix); however, the requirement to heat the feed stream to maintain the water vapour pressure gradient can be the cause of a significant loss of organic volatiles.

Concentration by OD is an emerging membrane technique based on the use of an hydrophobic microporous membrane to separate two liquid phases that differ greatly in terms of solute concentration (Alves, Koroknai, Bélafi-Bakó, & Coelhoso, 2004; Alves & Coelhoso, 2006; Cassano et al., 2003; Hogan, Canning, Peterson, Johnson, & Michaels, 1998; Jiao, Cassano, & Drioli, 2004; Lebfevre, 1988; Shaw et al., 2001; Vaillant et al., 2001). The hydrophobic nature of the membrane prevents penetration of the pores by aqueous solutions, creating air gaps within the membrane. The difference in solute concentration, and consequently in water activity between the two sides of the membrane, induces a vapour pressure difference causing a water vapour transfer across the pores from