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Athermal concentration by osmotic evaporation of roselle extract, apple and grape juices and impact on quality

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ABSTRACT

Osmotic evaporation (or osmotic distillation) was carried out on roselle extract, apple and grape juices. The industrial pilot plant used had a hydrophobic, polypropylene, hollow-fiber membrane with an area of 10.2 m^2 and an average pore diameter of 0.2 μm. It was suitable for concentrating vegetable extracts and fruit juices, and controlled various parameters such as temperature, flow velocity, and brine concentration. The final total soluble solids (TSS) contents achieved were 660, 570, and 610 g kg^{-1} for grape juice, apple juice, and roselle extract, respectively. Temperature and concentration of solutions significantly influenced evaporation flux, which, for roselle extract, was 1.5 kg h^{-1} m^{-2} at 610 g TSS kg^{-1} and 45 °C. The physico-chemical, biochemical, and aromatic qualities of concentrates obtained by osmotic evaporation were much higher than those of thermal concentrates, and close to those of the initial products.

Industrial relevance: Membrane processes are increasingly used to concentrate thermo-sensitive fruit juices and plant extracts. Their capacity to operate at moderate temperatures and pressures means that their energy consumption is low, while they produce good quality concentrates. Nonetheless, the main disadvantage of baromembrane processes is their inability to reach the concentration levels standard for products of thermal evaporation because of limitations resulting from high osmotic pressure. Actually, reverse osmosis membranes and equipment limit the final concentration of fruit juices to about 25–35°Brix. Osmotic evaporation has attracted considerable interest, as it can concentrate juices to as much as 65°Brix. This process, when applied to various juices, better preserves the quality of raw materials. However, because of the geometrical limitations of commercially available membranes and modules, juices must first be clarified. To our knowledge, only a few studies on osmotic evaporation have so far been conducted at a semi-industrial scale and never with roselle extracts.

1. Introduction

The preservation, during stabilization, of nutritional, sensorial, antioxidant, and pharmaceutical properties of fruit juices and plant extracts has become a major challenge in food science. Classical processes, such as thermal pasteurization and concentration by vacuum evaporation, significantly change the quality of fresh fruit juices and plant extracts. Temperatures higher than 50 °C degrade sensorial properties and nutritional compounds such as vitamins, and induce a loss of aroma compounds, leading to a partial loss of the fresh juice flavor (Cisse, Vaillant, Perez, Dornier, & Reynes, 2005; Shaw et al., 2001; Vaillant et al., 2001).

Research on technological alternatives to thermal processing has become an important issue. Membrane processes such as ultrafiltration, nanofiltration, reverse osmosis, and osmotic evaporation are today increasingly used to concentrate fruit juices and plant extracts. Their capacity to operate at moderate temperatures and pressures means that their energy consumption is low, while they produce good quality concentrates (Banvolgyi, Horvath, Stefanovits-Banyai, Bekassy-Molnar, & Vatai, 2009; Cassano, Jiao, & Drioli, 2004; Ding, Liu, Yu, Ma, & Yang, 2008; Hongvaleerat, Cabral, Dornier, Reynes, & Ningsanond, 2008). Nonetheless, the main disadvantage of baromembrane processes is their inability to reach the concentration levels standard for products of thermal evaporation because of limitations resulting from high osmotic pressure. Actually, reverse osmosis membranes and equipment limit the final concentration of fruit juices to about 25–35°Brix (Banvolgyi et al., 2009; Rodrigues et al., 2004).

Osmotic evaporation (OE), also called osmotic distillation, has attracted considerable interest (Girard & Fukumoto, 2000; Hogan,

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Canning, Peterson, Johnson, & Michaels, 1998; Jiao, Cassano, & Drioli, 2004), as it can concentrate juices to as much as 650 g total soluble solids (TSS) per kilogram (Cisse et al., 2005; Rodrigues et al., 2004; Vaillant et al., 2001). This process, when applied to various juices, better preserves the quality of raw materials (Cisse et al., 2005; Hongvaleerat et al., 2008; Vaillant et al., 2005). However, because of the geometrical limitations of commercially available membranes and modules, juices must first be clarified. To our knowledge, only a few studies on osmotic evaporation have so far been conducted at a semi-industrial scale (Cisse et al., 2005; Vaillant et al., 2001; Vaillant et al., 2005) and never with roselle extracts.

Roselle *(Hibiscus sabdariffa* L.) is a herbaceous plant cultivated largely in the tropics and subtropics of both hemispheres (Cisse, Dornier, Sakho, Ndiaye, Reynes & Sock, 2009). Belonging to the Malvaceae family, *H. sabdariffa* is known under different names, such as *bissap* in Senegal, *karkade* in North Africa, *roselle* or *sorrel* in English, and *flor de Jamaica* in Central and South America. Aqueous extract from calyces of *H. sabdariffa* presents several interesting features. It is used worldwide to produce drinks and is a source of natural food coloring because of its high anthocyanin content (Cisse, Dornier, et al., 2009; Juliani et al., 2009). *Hibiscus* extracts are reported as having medical properties such as decreasing serum cholesterol in humans and animals (Hirunpanich et al., 2006; Lin et al., 2007), protecting the liver against oxidation stress (Liu et al., 2006), having antihypertensive and cardioprotective effects (Odigie, Ettarh, & Adigun, 2003), and attenuating nephropathy in diabetes (Lee et al., 2009). Most nutritional and functional properties of Roselle extracts can be attributed to its very high content of anthocyanin acting probably in synergy with other compounds. The main problem, during thermal processing of Roselle, is that high temperatures drastically degrade anthocyanins and also reduce their stability during storage (Cisse, Vaillant, et al., 2009).

This paper evaluates the potential of using osmotic evaporation to concentrate roselle extract, apple and grape juices. The process is evaluated in terms of performance and impact on product quality and compared with vacuum evaporation.

2. Materials and methods

2.1. Raw materials

To prepare roselle extract, dried calyces of Senegalese-grown Thai variety were mixed with cooled demineralized water at a mass ratio of calyces to water at 1:5. After soaking for 3 h, the extract was filtered, first through a stainless steel sieve (1 mm) and then through a polyester bag-filter system with a micron rating of 5 µm (GAF, Belgium). The extract was then stored at 4 °C until used. Industrial pasteurized apple and grape juices were purchased. Both juices were completely clear and were probably clarified. In accordance with the European legislation, these juices only contained the aroma compounds of the fruits.

2.2. Concentration

An industrial pilot plant, developed by EURODIA Industrie (Wissous, France) and CIRAD, was used (Fig. 1). The plant featured a hydrophobic, polypropylene, hollow-fiber membrane with a total area of 10.2 m^2 and an average pore diameter of 0.2 µm. The supply tank for the juice had a 50 L capacity, while the brine circuit had a total volume of 70 L. The juice or extract to be concentrated circulated inside the hollow fibers.

The concentrate loop was continuously fed with roselle extract or fruit juice, and the concentrate extracted continuously, once the desired level of total soluble solids was reached. Calcium chloride solution, that is, the brine solution, circulated concurrently on the other side of the membrane. Electrical conductivity of the juice was continuously monitored during concentration to ensure membrane integrity and hydrophobicity, and detect any possible salt leakage through the membrane. During the trials, $CaCl_2$ crystals were added at 5.5 to 6.0 mol L^{-1} to maintain the brine solution at near saturation.

According to Cisse et al. (2005) and Vaillant et al. (2001) this configuration better preserves the concentrate's aroma compounds. Brine temperature was maintained between 37 and 40 °C by cooling. The temperature of solution to be concentrated was maintained at 35 ± 2 °C. Pressure and temperature values at the membrane's inlet and outlet were recorded, pressure varying by $\pm 2\%$ and temperature by ± 1 °C. The average evaporation flux (J_w) was measured on the brine loop.

The brine tank had an opening in the upper layer and water, evaporated from the product being concentrated, condensed in the brine, resulting in increased brine volume. Brine overflow was then collected in a container placed on a balance (PRECIA MOLEN SA, Privas, France) with a maximum capacity of 30 ± 0.01 kg. Mass differences, reported regularly every 5 min between two successive measurements, gave the evaporation flux. At the end of the trials, the diluted brine was recovered and concentrated by heating at atmosphere pressure until salts crystallized. The crystals were kept for reuse in further trials.

To compare osmotic evaporation with a reference thermal process, roselle extract, grape and apple juices were also concentrated by

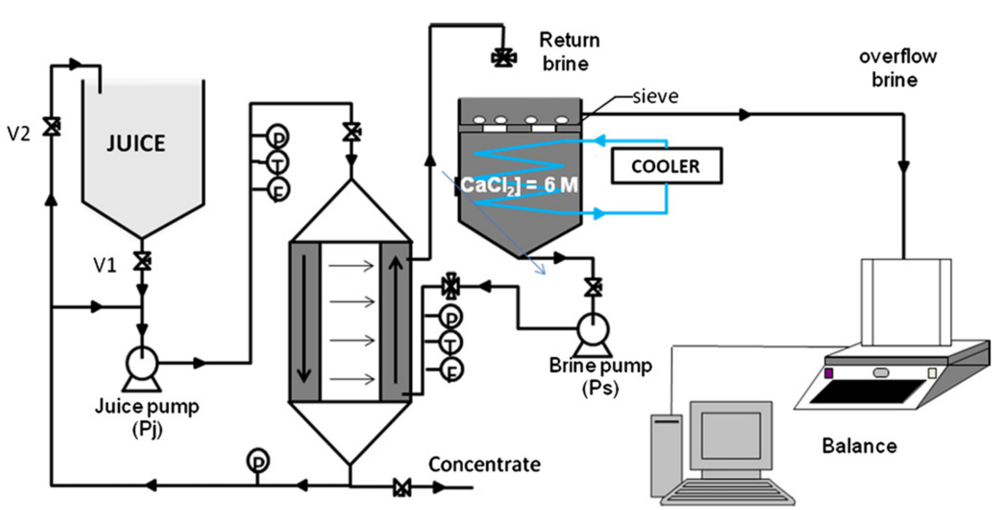

Fig. 1. Schematic of the pilot plant of osmotic evaporation used for concentration of roselle extract, apple and grape juices.