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Effect of a combination of electrodialysis with bipolar membranes and mild heat treatment on the browning and opalescence stability of cloudy apple juice

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Abstract

The purpose of this work was to develop a process enabling the quick inactivation of the polyphenol oxidase and pectin methylesterase enzymes, which are present in cloudy or unclarified apple juice; These enzymes are respectively responsible for enzymatic browning and opalescence instability. In order to fulfill this objective, acidification of the apple juice to pH 2.0 was conducted by electrodialysis (bipolar–anionic membranes) followed by mild heat treatment at temperature of 40, 45 and 50 °C for a duration of 0–60 min. Then, juice pH was readjusted to its initial value by electrodialysis with bipolar–anionic membranes. It was shown that a mild heat treatment at 45 °C for 5 min performed on the acidified juice represents an appropriate condition to quickly inactivate the enzymes. Furthermore, the organoleptic properties of the juice after treatment were found to be preserved and the adjusted juice (pH readjusted to its initial value) shows a better color than an untreated apple juice. Opalescence of the adjusted juice was also more stable than for an untreated cloudy apple juice, when stored at 4 °C for 3 months.

Keywords: Browning; Cloudy apple juice; Electrodialysis; Mild heat treatment; Opalescence stability

1. Introduction

Cloudy or unclarified apple juice contains significant quantities of suspended pulp and is perceived as a natural food product that supplies dietary fiber and important nutrients. However, it is very difficult to produce superior quality juice since cloudy apple juice is very sensitive to enzymatic browning because it contains considerable quantities of polyphenols and polyphenol oxidase (PPO) (Lea, 1990). PPO refers to a group of copper-containing enzymes that catalyze the oxidation of phenolic compounds to *o*-quinones, which then polymerize to form complex dark pigments, thereby changing the color and aroma of the juice (Macheix, Fleuriet, & Billot, 1990). In addition, it is very difficult to produce a cloudy or unclarified apple juice with good opalescence stability due to the presence of pectin methylesterases (PME). The pectin molecules present in suspension are degraded by the PME enzymes resulting in a loss of opalescence stability (Beveridge, 1997).

Zémel, Sims, Marshall, and Balaban (1990) showed that it is possible to irreversibly inhibit PPO by acidifying the cloudy apple juice to pH 2.0, using HCl, and readjusting the juice pH at its initial value (~3.35), by addition of NaOH. The PME can also be inactivated at low pH (pH 2.0) as shown by Owusu-Yaw, Marshall, Koburger, and Wei (1988) for the case of orange juice. The drawbacks of this approach are the dilution associated with the addition of acid and base, and the salty aftertaste.

Based on these observations, Tronc (1996) and Tronc, Lamarche and Makhlouf (1997 and 1998) have demonstrated the feasibility of acidifying cloudy apple juice using

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electrodialysis (ED) with bipolar–cationic membranes. Readjustment of pH to its initial value was achieved by ED with bipolar–anionic (BP–A) membranes. However, the process was found too lengthy and required addition of exogenous KCl in the juice to reach pH 2.0. At this pH, the juice was kept one hour at room temperature to inhibit the enzymes. The adjusted juice (pH ~ 3.35), shows a PPO reactivation corresponding to 25% of its initial value (Tronc, 1996). Finally, from an industrial point of view, the energy required was too high (197 kWh/m^3 of juice) due to the large spacer (8 mm) used in the electrodialysis cell. However, they demonstrated that organoleptic properties of the juice were preserved.

In a more recent work, Lam Quoc, Lamarche, and Makhlouf (2000), improved the process by performing both acidification and pH readjustment steps using a BP–A configuration. Furthermore, thinner spacers (0.75 mm) were used in the electrodialysis cell and HCl was used as the base solution instead of KCl (Tronc, 1996; Tronc, Lamarche, & Makhlouf, 1998). The use of this configuration resulted in acceleration of the acidification step by a factor of 3, increasing the yield from 3.3 to 10 l of juice/m^2 membrane/min. Furthermore, the adjusted juice (pH ~ 3.35), shows only a very small reactivation of PPO activity of 0.8%, which is lower than the 25% level reported by Tronc (1996). The energy required by the process was also reduced to only 4–5 kWh/m^3 of juice, which is a very low energy consumption from an industrial standpoint. However, the main drawback of this approach remains the fact that the juice at pH 2.0 still had to be kept at room temperature for one hour to inhibit the enzymes.

In this paper, bipolar membrane ED followed by a mild heat treatment at 40, 45 or 50 °C for duration of 0–60 min was investigated to increase the rate of inactivation of the PPO and PME present in the unclarified apple juice. The influence of this treatment on the color and on the opalescence stability of the juice during storage will be discussed.

2. Materials and methods

2.1. Apple juice

Juice was extracted from McIntosh apples that had been stored commercially under controlled atmosphere. The apples were crushed and pressed in a crusher-press model no. EG 260-X6 (Goodnature Products Inc., Buffalo, United States) under maximum pressure of 1500 psi. About 2 l of juice was extracted from 4 kg of apples for each experiment. The freshly extracted juice underwent bipolar membrane ED treatment immediately.

2.2. Electrodialysis cell configuration

Electro-acidification was carried out using an ED-1-BP unit (100 cm^2 of effective electrode surface) from Electrosynthesis Co. (Lancaster, NY, USA), with spacing of 0.75 mm. The anode, a dimensionally stable electrode (DSA), and the cathode, a 316 stainless steel electrode, were supplied with the cell. The experiments were carried out using a BP–A configuration (Fig. 1) forming 10 compartments. A total of nine membranes were used: five bipolar membranes (Neosepta BP-1) and four anionic membranes (Neosepta AMX) from Tokuyama Soda Ltd. (Japan). This arrangement defines three closed loops containing the solution to alkalinize (0.1 N HCl), the cloudy apple juice to acidify and a 0.25 M K_2SO_4 solution used as rinsing solution for the electrodes. Each closed loop was connected to a separate external reservoir, allowing for continuous recycling. The electro-acidification was carried out with electrolytes volumes of 1 l for the solution to alkalinize (HCl), the apple juice to acidify and the K_2SO_4 solution. During treatment, juice temperature was maintained at 25 °C using a Haake G refrigerated bath (Haake, Berlin, Germany). The acidification of the juice by ED was conducted at a constant current density of 40 mA/cm^2. The ED configuration for pH readjustment was the same as that shown in Fig. 1. However, the juice and HCl compartments were reversed. During the acidification and pH readjustment steps, conductivity and juice pH were measured at 1–2 min intervals until the end of the treatments, along with applied voltage.

2.3. Protocols

2.3.1. Electrodialysis combined with mild heat treatment

The electro-acidified juices (pH 2.0) were subsequently heated at 40, 45 and 50 °C, as a function of time (0–60 min) to inhibit the PPO and PME enzymes. The heat treatments were done on 50 ml samples placed in a water bath with a thermostat and under agitation. At the end of the heat treatments, the samples were immediately cooled by immersion in ice/cold water. Samples were analysed for PPO and PME activities, color and where compared with an acidified juice (pH 2.0) kept at room temperature for the corresponding time.

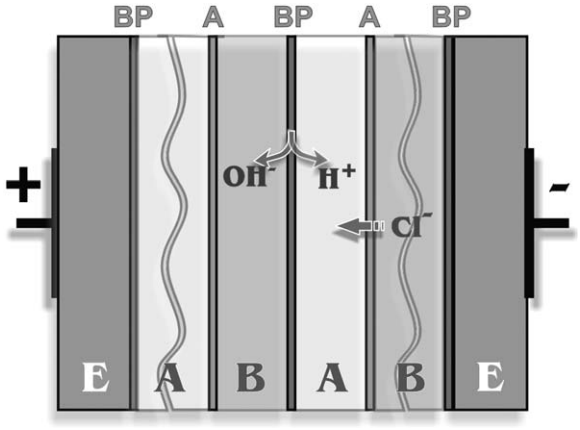

Fig. 1. Electrodialysis experimental systems: bipolar–anionic membrane configuration. Bipolar membrane (BP) and anionic membrane (A). Acidification step: A = Juice and B = HCl. Alkalinization step: A = HCl and B = Juice.