ABSTRACT – A 2^2 factorial design was used to analyze the effect of sodium chloride concentration and the solutions’ flow rate on the water transmembrane flux performances for jaboticaba concentration using forward osmosis. The statistical analysis showed that both process parameters presented significant effect (p<0.05) on water permeate flux. Comparing the FO juice with the fresh one, it was found that FO preserved the anthocyanin content and its antioxidant properties, although transport of sodium was observed in the reconstituted juice when it was concentrated by FO (12.9 mg of sodium equivalent per liter of juice). However, this salt transport does not seem to affect the nutritional quality of the jaboticaba juice. Thermal process for the beverage concentration implied on decrease of anthocyanins and antioxidant activity. Thus, results indicate that FO is an interesting alternative to be used as a pre-treatment for concentration of liquid foods.

RESUMO – Um planejamento fatorial 2^2 foi realizado para avaliar o efeito da concentração de cloreto de sódio e vazão das soluções no desempenho do fluxo de água transmembrana durante a concentração de suco de jabuticaba usando a técnica de osmose direta (OD). A análise estatística mostrou que ambos parâmetros do processo apresentaram efeito significativo (p <0,05) sobre o fluxo de permeado de água. Comparando suco concentrado por OD com o in natura, observado-se que a OD preservou as antocianinas e compostos com atividade antioxidante presentes no suco. Contudo, os resultados mostraram transporte de sódio no suco reconstituído (12,9 mg de sódio por litro de suco), mas que parece não afetar a qualidade nutricional do suco de jabuticaba. O processo térmico para a concentração do suco implicou em redução de antocianinas e atividade antioxidante no suco processado. Assim, os resultados indicam que OD é uma alternativa interessante para ser utilizado como um pré-tratamento para a concentração de alimentos líquidos.

KEYWORDS: jaboticaba juice, forward osmosis, concentration, sodium transport.

PALAVRAS-CHAVE: suco de jaboticaba, osmose direta, concentração, transporte de sódio.
1. INTRODUCTION

Nowadays, the consumption of nutritious, minimally and naturally processed foods has growth mainly due to the consumer’s concern about human health and nutrition. Jaboticaba (*Myrciaria jaboticaba*) is an anthocyanin-rich berry from southeastern Brazil. It is source of polyphenols, vitamins, minerals and natural antioxidant compounds, which present well documented beneficial properties (Leite-Legatti *et al*., 2012).

Liquid foods concentration is an important unit operation in the food industry whereas it reduces packaging costs and enhances microbiological and biochemical stability. Forward osmosis (FO), also known as direct osmosis, shows up as a promising membrane technology, due to it has the difference of the water chemical potential between two solutions, separated by a semi-permeable membrane, as the only driven force, which is expressed in terms of osmotic pressure (π). Thus, FO presents the advantages of working at room temperature, no requesting of high hydraulic pressure, low fouling tendency and an ease scale-up (Cath *et al*., 2006; Sant’Anna *et al*., 2012). In FO, the water is transported from the lower osmotic pressure solution (feed) to the higher osmotic pressure solution (draw solution, usually sodium chloride), concentrating the feed solution. Beyond the water transport from the feed to the draw solution, there is the reserve transport: salt from the draw solution to the feed (Babu *et al*., 2006). In this context, the objective of the present work is to evaluate FO process for concentrating jaboticaba juice and the effect of processing parameters on the transmembranal influx of water and salt. In addition, the quality of beverages concentrated by FO and thermal process were compared to the fresh juice.

2. MATERIAL AND METHODS

Jaboticabas (*Myrciaria jaboticaba*) were purchased in local market (Porto Alegre, RS, Brazil) and extraction of juices was performed in a laboratory scale hot steam drag and followed by pressing the fruits. Juice was vacuum filtered, and samples with total soluble solids of 12 °Brix were used in the concentration procedures.

The experiments were run on a bench-scale laboratory system, build of acrylic with channels (77 mm long × 26 mm wide × 3 mm deep) on both sides of the membrane unit. Membrane with a selective layer made of cellulose triacetate cast onto a non-woven backing consisting of polyester fibers individually coated with polyethylene was gently supplied by Hydration Technologies Innovation. The feed and draw solutions were run in closed loop and the membrane was oriented with the jaboticaba juice against the membrane selective layer and the sodium chloride solution against the membrane support layer.

In order to investigate the influence of FO process parameters on the water and salt transmembrane fluxes, a complete factorial design was carried out with the sodium chloride concentration and the solution’s flow rate as independent variables. Peristaltic pump with adjustable speed was used to pump both solutions at the same flow rate, varying between 50 to 200 mL min⁻¹, and sodium chloride at analytical grade as the draw solution in the concentration range of 2 to 6 mol L⁻¹. Both temperature solutions were kept constant at 25 °C by a water bath. Average water flux crossing the membrane to the draw solution was measured based on average weight gain in the first 5 h of osmotic process by a semi-analytical balance. Thermal concentration of jaboticaba juices was performed in a vacuum rotatory evaporator maintaining 0.2 L of sample at -450 mmHg of pressure and 90 °C.

After the concentration procedures the juices were reconstituted to the initial total soluble solid content (12 °Brix) and samples were analyzed about their pH, using digital pHmeter and total acidity by titration with 0.1 N sodium hydroxide (AOAC, 1984). The total phenolic content (TPC) of the beverages was determined by the Folin-Ciocalteau method described by Singleton and Rossi (1965) and expressed as mg gallic acid equivalent per mL of juice (mg GAE mL⁻¹). Monomeric anthocyanins (MA) were determined...
using the pH differential method (Wrolstad et al., 2005) and expressed as mg of cyanidin 3-glucoside per mL of juice (mg C3G mL⁻¹). The antioxidant activity (AA) of the jaboticaba juices was expressed by the capability scavenging ABTS radicals like proposed by Re and co-workers (1999) and the results were expressed as µM of Trolox equivalent per mL of juice (µM TE mL⁻¹). The degree of non-enzymatic browning (NEB) was measured by following Brandelli and Lopes method (2005). Salt concentration was measured by atomic absorption spectrophotometer with flame atomization.

The data from factorial design experiments were evaluated with the aid of Statistica 11 (StatSoft, US). Obtained values of the physical and chemical properties of the jaboticaba juices were compared using Tukey’s and differences were considered statistically significant, when \( p<0.05 \).

### 3. RESULTS AND DISCUSSION

Jaboticaba juice utilized in the present work presented, in wet basis, 89.8% of humidity, 9.8% of carbohydrates, 0.1% of protein and 0.33% of ashes. Concentration of lipids was below the detection limit. Statistical analysis of the results showed that, in the range studied, the two variables had a significant effect \((p<0.05)\) on the water permeate flux. The interaction between the \( \Delta \pi \) and solution’s flow rate did not present significant impact \((p>0.05)\) on the water flux performance. The draw solution concentration is bonded to the osmotic pressure difference, which is the driving force of the osmosis process, thereat, the increase of the parameter implied on increase of the water transmembrane flux. An increasing on the flow rate alters the hydrodynamic boundary layer thickness, reducing the internal concentration polarization in the draw solution side and increasing the brine concentration in the dense membrane interface, what implies in a driving force enhance. Still, in the feed side, higher flow rate induces a reduction of external concentration polarization and higher shear strengths on the membrane surface, which may imply on higher osmotic driving force (Cath et al., 2006). By this way, the increase on the sodium chloride concentration and solution’s flow rate increased the water transmembrane flux significantly \((p<0.05)\). Results show that higher water permeate flux when draw solution of 6 mol L⁻¹ of sodium chloride was used flowing at 200 mL min⁻¹. When brine concentration of 2 mol L⁻¹ was used as draw solution, lower water flux was obtained.

In relation to the juice quality parameters, the Table 1 presents the physicochemical properties of fresh and reconstituted juices after thermal and FO concentration. The titratable acidity differed significantly \((p<0.05)\) for reconstituted juices with values of 0.93, 0.98 and 0.98 g acid per 100 mL of juice for fresh, FO and thermal concentrated jaboticaba beverage, respectively. This is attributed to the retention of juice components. Organic acids may be transported or degrade when submitted to concentration procedures leading to an increase of acidity on final product. Although all juices pH remained the same due to the high solution buffer power.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Fresh</th>
<th>FO</th>
<th>Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>3.49±0.005</td>
<td>3.47±0.007</td>
<td>3.49±0.008</td>
</tr>
<tr>
<td>TA (g acid/100 mL juice)</td>
<td>0.93±0.012ᵃ</td>
<td>0.98±0.016ᵇ</td>
<td>0.98±0.011ᵇ</td>
</tr>
<tr>
<td>TPC (mg GAE mL⁻¹)</td>
<td>2.65±0.06ᵃ</td>
<td>2.844±0.12ᵃ</td>
<td>2.743±0.06ᵃ</td>
</tr>
<tr>
<td>MA (mg C3G mL⁻¹)</td>
<td>0.100±0.002ᵃ</td>
<td>0.097±0.003ᵃ</td>
<td>0.073±0.003ᵇ</td>
</tr>
<tr>
<td>AA (µM TE mL⁻¹)</td>
<td>11348.71±182.75ᵃ</td>
<td>11059.63±162.96ᵃ</td>
<td>9098.82±419.03ᵇ</td>
</tr>
<tr>
<td>NEB (Abs₄₂₀nm)</td>
<td>0.580±0.006ᵃ</td>
<td>0.591±0.011ᵃ</td>
<td>0.658±0.014ᵇ</td>
</tr>
<tr>
<td>Sodium content (mg L⁻¹)</td>
<td>1.7±0.3ᵃ</td>
<td>12.9±0.5ᵇ</td>
<td>1.8±0.1ᵃ</td>
</tr>
</tbody>
</table>

ᵃᵇᶜ Different superscripts in the same column indicate statistical differences \((p<0.05)\).
TPC in the fresh juice was 2.651 mg GAE mL\(^{-1}\) and was not significantly affected \((p>0.05)\) by the concentration processes. MA, on the other hand, were significantly sensitive \((p<0.05)\) to heat treatment. It happens according the methodology to assay total phenolics, it quantifies all phenolic forms of anthocyanins, as chalcones forms that occur with ring opening. While in the pH differential assays the polymerized anthocyanin pigments and NEB pigments do not exhibit reversible behavior with pH and they are thus excluded from the absorbance calculation (Shoemaker et al., 2005) Wrolstad et al., 2005). Similar behavior was observed on compounds with antioxidant capability through the scavenging capacities of ABTS radicals. After FO process fresh and reconstituted jaboticaba juices presented equal antioxidant capability \((p>0.05)\), meanwhile when the beverage was exposed to temperature of 90 ºC the property decreased significantly \((p<0.05)\) to 9098.82 µM TE mL\(^{-1}\). The thermal process occasioned the increase of NEB due to the formation of compounds of the Maillard reaction and the decline of color index, color density and antioxidant capacity. As deduced from the antioxidant capacity value and anthocyanin content, the loss of anthocyanin bioactivity could not be compensated by the antioxidant capacity of newly formed colorless phenolics and NEB upon heating (Nayak and Rastogi, 2011).

In the reconstituted juice, after the membrane concentration, the transport of salt was observed in the reconstituted juice when concentrated by FO. Sodium content reached values of 12.9 mg Na L\(^{-1}\), and in the fresh juice, 1.7 mg Na L\(^{-1}\). The Institute of Medicine (2006) set the Tolerable Upper Intake Level (UL) at 2300 mg per day. The UL is the highest daily nutrient intake level that is likely to pose no risk of adverse health effects (e.g., for sodium, increased blood pressure) to almost all individuals in the general population, which shows that the salt transport during FO seems not to affect the nutritional quality of the jaboticaba juice.

4. CONCLUSION

Sodium chloride concentration and draw solution concentration presented significant effect on water transmembrane flux for jaboticaba juice concentration by FO. Thermal concentration showed to decrease anthocyanin and compounds with antioxidant capability, beyond of changes on beverage color properties in relation to the fresh juice. At present this study, it was observed that FO preserved, in general, the nutraceutical and organoleptic characteristics of the jaboticaba juice, showing that FO is an interesting technique to be used as alternative in the food industry.

REFERENCES


