Impact of selected combinations of non-thermal processing technologies on the quality of an apple and cranberry juice blend

Irene M. Caminiti, Francesco Noci, Arantxa Muñoz, Paul Whyte, Desmond J. Morgan, Denis A. Cronin, James G. Lyng*

UCD Agriculture and Food Science Centre, School of Agriculture, Food Science and Veterinary Medicine, College of Life Sciences, University College Dublin, Belfield, Dublin 4, Ireland

**A R T I C L E   I N F O**

Article history:
Received 19 March 2010
Received in revised form 18 June 2010
Accepted 27 July 2010

Keywords:
Apple juice
Cranberry juice
Hurdle technology
Ultraviolet
Manothermosonication
High intensity light pulses
Pulsed electric fields
Non-thermal processing
Sensory analysis

**A B S T R A C T**

A blend of apple and cranberry juice was processed by a combination of a light-based technology (ultraviolet light (UV) (5.3 J/cm²) or high intensity light pulses (HILP) (3.3 J/cm²)) in combination with pulsed electric fields (PEF) (34 kV/cm, 18 Hz, 93 μs) or manothermosonication (MTS) (5 bar, 43 °C, 750 W, 20 kHz). Selected physical and chemical attributes were evaluated pre- and post-processing, and the sensory attributes of non-thermally treated samples were compared to conventional pasteurisation (26 s, 72 °C). No significant changes were found in non-enzymatic browning, total phenolics and antioxidant activity of the juices. UV + PEF and HILP + PEF treatments did not affect the colour of the product and HILP + PEF processing retained more monomeric anthocyanins than any other combined treatment. Sensory analysis showed that UV + PEF and HILP + PEF combinations did not impact on odour and flavour of the juice, while combinations that included MTS adversely affected those attributes.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

During the last few decades, research on food preservation has focused on meeting consumer demands for more natural and healthier food, with the interest moving from conventional thermal treatments towards non-thermal preservation techniques. While thermal processing may cause some adverse effects on the nutritional and/or organoleptic attributes of food, non-thermal technologies have the potential to ensure safety while maintaining the fresh-like characteristics of the food product. A recent trend in food preservation, known as hurdle technology, involves the application of a deliberate and intelligent combination of non-thermal processes, which may also be combined with conventional preservation factors (e.g. pH, temperature, water activity, redox potential) (Leistner, 1999). The choice of hurdles is made according to their mode of inactivation of the microbial cell. With combined treatments, synergies are more likely if the individual hurdles target different functions within the cell, thus permitting a gentler preservation treatment, with potentially less impact on the quality of the product (Leistner, 2000).

Non-thermal processing technologies include the application of high-voltage pulsed electric fields (PEF), high hydrostatic pressure, ultraviolet light (UV), high intensity light pulses (HILP) and manothermosonication (MTS) (Butz & Tauscher, 2002; Gould, 2001). Combinations of these have been recently exploited for microbial and enzymatic inactivation in fruit juices and milk (Noci, Walking-Ribeiro, Cronin, Morgan, & Lyng, 2009; Ross, Griffiths, Mittal, & Deeth, 2003; Walking-Ribeiro et al., 2009).

Inactivation of microorganisms exposed to high-voltage PEF is related to the electromechanical instability of the cell membrane with irreversible pore-formation (electroporation) occurring at trans-membrane potentials in excess of 1 V (Barbosa-Canovas, Tapia, & Cano, 2004). The phenomenon of cavitation (formation, evolution and implosion of bubbles) is thought to be the major cause of the instability of the cell membrane when ultrasound (US) is employed at high power/low frequency (20–100 kHz) conditions (Knorr, Zenker, Heinz, & Lee, 2004). In addition, the combination of US with mild heating and moderate pressures (MTS) has been shown to enhance microorganism and enzyme inactivation (Lopez et al., 1994; Sala, Burgos, Condon, Lopez, & Raso, 1995). UV treatment is based on the bactericidal action of short wave UV light (UV-C, 200–280 nm), which can be absorbed by the DNA of microorganisms, impairing the reproducing processes of the cell.

* Corresponding author. Tel.: +353 01 7167710; fax: +353 01 7161147. E-mail address: james.lyng@ucd.ie (J.G. Lyng).

0308-8146/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2010.07.096
(Lopez-Malo & Palou, 2004). The common UV systems used to disinfect water, air and surfaces, contain low-pressure vapour mercury lamps, which are characterised by a peak of emission in the germicidal region at 254 nm. The photochemical effect on DNA molecules is also thought to be the main inactivation mode for HILP technology. In this case, the broad spectrum (200–1100 nm) emitted by a Xenon lamp is produced in very short (100–400 μs) and intense pulses. The infrared region (800–1100 nm) may induce a photothermal effect, which could further destabilize the microorganisms by damaging the cell membrane, especially at high fluence conditions (above 0.5 J/cm²) (Gómez-López, Ragaert, Debevere, & Devlieghere, 2007).

In the beverage area, the antimicrobial impact of combined non-thermal technologies has received more attention in published research than their potential benefits on product quality (Ross et al., 2003). The aim of the present work was to evaluate the effect of the application of selected combined non-thermal treatments (UV, HILP, PEF, MTS) on the chemical, physical and sensory attributes of a blend of apple and cranberry juice. The selected treatments (UV, HILP, PEF, MTS) on the chemical, physical and sensory attributes of a blend of apple and cranberry juice. The selected combinations were applied under conditions that proved (in work to be reported elsewhere) to reduce Escherichia coli and Pichia fermentans in the chosen fruit blend, by amounts in excess of the 5 log cycle reduction required by the FDA for fruit juice processing (FDA, 2001).

2. Materials and methods

2.1. Apple and cranberry juice

A blend of fresh apple and cranberry juice (90:10 v/v) was obtained from a local juice manufacturer (Keelings, Dublin, Ireland) and stored at −20 °C pre- and post-processing. The blend was prepared from freshly pressed fruit. The apples were squeezed in a filter press, while the cranberries were crushed and then filtered. Prior to treatment, the juice was further filtered through a 425 μm steel sieve and then collected for subsequent analysis of physico-chemical parameters. For comparative purposes, an untreated sample was similarly retained and assayed.

2.2. Experimental treatments

The apple/cranberry juice was treated by paired combinations of selected non-thermal technologies. A light-based technology (either UV or HILP) was employed as the first hurdle followed by either US or PEF, resulting in four different pairings of 2 technologies. Each technology was run in continuous mode. When necessary, a holding vessel was employed between the two hurdles, for example, due to a disparity in flow rates. Experimental treatments were carried out in triplicate (n = 3). Thermal pasteurisation was also applied to the juice, while an untreated juice was used as control.

2.3. Processing equipment and conditions

2.3.1. Ultraviolet light

The UV rising film reactor was based on a tubular reactor manufactured by C-Tech (Chester, UK), with two concentric tubes arranged vertically and a 30 W low-pressure mercury lamp (70 cm long) enclosed within the inner tube. The juice was pumped through a 1 mm thick annular space between the tubes (quartz inner, o.d. 35 mm, glass outer, i.d. 37 mm) and subsequently collected before being processed in the second treatment phase. The radiant exposure (dosage), defined as the energy delivered per unit surface area of the UV reactor, was calculated using the following formula.

\[ D = I \times t \]  

where \( I \) was the measured irradiance of the lamp (0.177 W/cm²) and \( t \) was the exposure time (30 s). \( I \) was measured using an UV–VIS radiometer (Model No RM-21, Dr. Gröbel UV-Elektronik GmbH, Germany) supplied with a UV-C sensor (spectral range from 200 to 280 nm) placed at the same distance from the UV lamp as the juice. The calculated energy dosage was, thus, 5.3 J/cm².

2.3.2. High intensity light pulses

Pulsed light treatment was applied using a pulsed light sterilization system (Steri-Pulse XL 3000, Xenon Corp., MA, USA) consisting of a control module, a lamp housing containing a Xenon flashlamp, and a sterilization chamber. A continuous flow system was developed in-house and located within the sterilization chamber. Juice was pumped (Section 2.3.1) through two quartz tubes (length 30 cm, 1 mm i.d.) positioned at a distance of 1.9 cm from the lamp (Fig. 1). The tubes were located on a grooved (300 mm length x 3 mm diameter) aluminium assembly through which coolant (ethylene glycol at −10 °C) was circulated to prevent overheating of the juice. To minimise temperature rise, the product was cooled pre- and post-processing with cooling coils submerged in iced water, in addition to in-process cooling within the flow cell system. The post-processing temperature typically did not exceed 30 °C. The Xenon source produced light pulses of 360 μs width at a frequency of 3 Hz and delivered radiant energy of 1.213 J/cm² per pulse. The total cumulative length of exposed tubing was 40 (2 × 20 cm) cm and the total energy dosage was 3.3 J/cm², based on a sample flow rate of 20.8 ml/min.

2.3.3. Pulsed electric fields

The lab-scale PEF system described by Noci et al. (2008) was used. The device employed monopolar pulses at a frequency of 18 Hz with a pulse width of 1 μs and a field strength of 34 kV/cm. Total treatment time was 93 μs based on a residence time of 5.2 s in the processing chamber.

2.3.4. Manothermosonification

The apple and cranberry juice were processed using an ultrasonic processor (Hiescher UIP1000hd, Teltow, Germany) supplied with a booster (B2-1.8) and a sonotrode (BS2d40), creating sonic waves of 23 μm amplitude and 20 kHz frequency. A stainless steel flow cell (Model No. FC100L1 K-1S) was used to perform continuous sonication processing. The power output was 750 W, and the pressure applied was 4 bar. The juice was pre-heated to 43 °C through a stainless steel coil submerged in a water bath. After processing (8.4 min residence time), which gave an end temperature of 58 °C, the product was cooled by passing though a coil immersed in iced water. A cooling jacket incorporating a re-circulating refrigerant (ethylene glycol) kept at −15 °C was used to control the temperature during the actual sonication process.

2.3.5. Thermal pasteurisation

The product was pasteurised using a tubular heat exchanger (Model No. FT74T, Armfield, Ringwood, UK) with the temperature of the holding tube set at 72 °C, a residence time of 26 s and a come-up time of 3.5 min.

Before and after use, all equipment was thoroughly flushed with water and cleaned for 20 min with a 2% w/v NaOH solution. After rinsing with water, a 5% (v/v) hypochlorite-based solution (Milton) was passed through each device for 15 min for disinfection purposes, followed by a final rinse with water.
2.4. Chemical and physical analyses

2.4.1. pH, °Brix and colour

pH was measured with a pH meter (Model No. 9450, Unicam Ltd., Cambridge, UK), and soluble solids were evaluated as °Brix at 20 °C using a hand held refractometer (0–50% Sugar Refractometer, Bellingham & Stanley Ltd., Tunbridge Wells, UK). The colour components L (lightness), a (redness) and b (yellowness) of the Hunter Lab colour space were measured with a tristimulus colorimeter (Model No. CR 400/410 Chroma Meter, Minolta, Osaka, Japan) and the total colour difference (ΔE) calculated using Eq. (2).

\[
\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}
\]  

2.4.2. Non-enzymatic browning index (NEBI) and total phenols

The method of Meydav, Saguy, and Kopelman (1977) was used to determine the NEBI of the juice pre- and post-processing. The total phenolic content was determined by the Folin–Ciocalteu colorimetric method (Singleton & Rossi, 1965). The juice was centrifuged for 20 min at 8700 g (Model No. J2-HS, Beckman Instruments Inc. Palo Alto, CA, USA) to remove any remaining pulp and 1 ml of supernatant was mixed to 5 ml of 0.2 N Folin Ciocalteu reagent (Sigma–Aldrich) and 4 ml of 7.5% sodium carbonate (Sigma–Aldrich). The solution was allowed to stand for 2 h at room temperature and away from strong light. The absorbance was measured at 765 nm using a UV–Vis spectrophotometer (Model No. UV Mini 1240, Shimadzu, Japan) and results were expressed as gallic acid equivalents (GAE, mg/l).

2.4.3. Total antioxidant activity

The total antioxidant activity was determined according to the method of Kim, Lee, Lee, and Lee (2002). AAPH (2,2’-Azobis(2-methylpropionamidine) dihydrochloride, Sigma–Aldrich) 1.0 mM was mixed with 2.5 mM ABTS (2,2’-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt, Sigma–Aldrich) in phosphate buffered saline (PBS) solution (100 mM potassium phosphate buffer (pH 7.4) containing 150 mM NaCl). The mixture was heated at 68 °C for 1 h and mixed every 15 min. The resulting blue-green ABTS⁺ solution was then filtered (No.1 Whatman filter paper) to remove the undissolved AAPH and the absorbance adjusted to a value of 0.8 ± 0.02 at 734 nm. 0.05 ml of the filtered sample (cheese cloth) was added to 2.45 ml of radical solution and the mixture incubated, protected from light, in a water bath at 37 °C for 10 min. The decrease of absorbance at 734 nm was measured after exactly 10 min. A control consisted of 0.05 ml of distilled water and 2.45 ml of ABTS⁻ solution. Standard Trolox solutions were also evaluated and the ABTS radical scavenging activity of the juice was expressed as Trolox Equivalent Antioxidant Capacity (TEAC) (mM).

2.4.4. Anthocyanins

Total monomeric anthocyanins (TMA) were determined using the pH differential method of Giusti and Wrolstad (2001). This

Fig. 1. (a) Schematic diagram of the High Intensity Light Pulse (HILP) processing system; (b) Top view of the continuous flow HILP chamber; (c) Side view of the continuous flow HILP chamber.
method measures the absorbance at two pH values (pH 1 and 4.5) and is based on the change in anthocyanin structure as a function of pH. Absorbances were measured at 510 and 700 nm with a UV–Vis spectrophotometer. The monomeric anthocyanin pigment was expressed as cyanidin-3-glucoside units (mg/l). In addition, the percentage of the colour contributed by polymerised anthocyanin–tannin complexes was measured by exploiting the bleaching reaction of monomeric anthocyanins by bisulphite (Giusti & Wrolstad, 2001).

2.5. Sensory analysis

A sensory evaluation of the treated juices was carried out using 35 untrained panellists. The pasteurised product was used as the control sample. Aliquots of 20 ml of juice were given to the assessors in a randomized order in clear plastic cups with a random 3-digit code number. Unsalted crackers and still water (Ballygowan, Newcastle West, Co. Limerick, Ireland) were served for cleansing the palate between samples. Panellists evaluated appearance, odour, flavour, sweetness, acidity and overall acceptability using a 1–9 hedonic scale, with 1 corresponding to “dislike extremely” and 9 to “like extremely”.

2.6. Statistical analysis

All data were subjected to statistical analysis using SAS 9.1 (SAS Institute Inc., Cary, North Carolina, USA). The experimental treatments were compared using a one-way analysis of variance. Significant differences (p < 0.05) between treatment means were determined by the Student’s t test.

3. Results and discussion

3.1. Physical and chemical analyses

All experimental treatments showed no effect on pH or “Brix of the juice (mean values 3.18 and 7, respectively). The results of the colour measurements are shown in Table 1. Juice processed by the non-thermal combinations HILP + PEF and UV + PEF was not significantly different from the untreated sample in terms of colour attributes. The total colour difference (ΔE) values fell within the “slightly noticeable” range (0.5–1.5) according to the classification of Cserhalmi, Sass-Kiss, Tóth-Markus, and Lechner (2006), while well visible changes (3.0–6.0) occurred when the juice was treated by the combinations HILP + MTS and UV + MTS. Both treatments involving the use of MTS as a second hurdle induced a darkening of the product, which was reflected in a significant decrease (p < 0.001) in the L value, compared to the thermally pasteurised sample. The lightness of these latter samples was not significantly different from the untreated control (p > 0.05). Significant decreases (p < 0.001) of 37% and 34% were observed in the α parameter of the HILP + MTS and UV + MTS treated samples, respectively, showing that juice processed by the selected combinations was less red than the control. A tendency towards a blue colour was suggested by the significant (p < 0.001) decreases in the b values from −1.88 (untreated control) to −3.73, and −3.57 for the aforementioned samples. Colour measurements performed on the juice after processing by the first hurdle only showed that the product was not significantly different from the untreated sample, regardless of the nature of the hurdle (UV or HILP). This result suggests that the MTS treatment was responsible for the colour changes observed in the product. In a similar study, Cheng, Soh, Liew, and Teh (2007) found that guava juice treated by US, alone or in combination with carbonation, showed a significant change in the ΔE value, due to a decrease in lightness and an increase in a and b values. In a study conducted by Zenker, Heinz, and Knorr (2003) the colour of orange juice was significantly changed (ΔE = 2.56) by TS processing (acoustic energy input of 1296 kJ/kg). The product showed lower CIE a° and b° values, in agreement with the results of the current work; however a brightening effect was also observed. Tiwari, Muthukumarappan, O’Donnell and Cullen (2008) studied the colour degradation of sonicated (20 kHz, 1500 W US processor) fresh orange juice and found that the lightness attribute changed with the amplitude level applied; in particular, an increase of the L° value was reported when the minimum 40% amplitude was applied, while a decrease occurred at higher amplitude levels up to 100%, which is similar to the results obtained in the present study. Even though the apple and cranberry juice used in this work were filtered before processing, small pulp particles (<425 μm) were present in the product, which became darker after sonication, possibly contributing to the overall colour changes observed.

The NEBI is considered a quality index of food products and it is linked to reactions that can cause colour changes, off-flavours and nutrient losses. In the present study, no significant changes were found in the NEBI (Table 2) of the apple and cranberry juice processed by any of the combinations of non-thermal technologies, indicating that degradation reactions that would promote the development of browning components did not occur to any significant extent during the non-thermal processes employed. Aguiló-Aguayo, Oms-Oliu, Soliva-Fortuny, and Martín-Belloso (2009) found that the NEBI of strawberry juice treated by bipolar square wave PEF at 35 kV/cm for 1700 μs was not significantly different from that of the unprocessed juice, whereas a thermal treatment at 90 °C for 60 s caused a significant browning of the same product. Similarly, Walkling-Ribeiro et al., 2009 reported that reconstituted orange juice processed by PEF (30–40 kV/cm; 1 μs pulse width; frequency of 15 Hz), TS (55 °C, 30 kHz for 10 min), or a combination of these technologies showed comparable NEBI values to unprocessed juice, while the conventionally pasteurised sample (94 °C for 26 s) showed a significantly higher value. In the present study, a heat treatment less severe (72 °C for 26 s) than the aforementioned did not cause any significant change in NEBI compared to the untreated control.

Phenolic compounds are present in considerable amounts in apple and apple products and are known to be the major cause of their antioxidant capacity and also contribute to their sensory properties (Khanizadeh et al., 2008). Heat treatments have been shown to significantly decrease the concentration of polyphenols in apple juice, as reported by Aguilar-Rosas, Ballinas-Casarrubias, Nevarez-Moorillon, Martin-Belloso, and Ortega-Rivas (2007), who

<table>
<thead>
<tr>
<th>Treatment</th>
<th>L</th>
<th>a</th>
<th>b</th>
<th>ΔE&lt;sup&gt;A&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL</td>
<td>17.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>11.9&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.17&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>-</td>
</tr>
<tr>
<td>PASTEURISED</td>
<td>17.2&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>11.7&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.04&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>0.96&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP</td>
<td>17.3&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.07&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>0.66&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP + PEF</td>
<td>17.3&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>11.9&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.05&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>0.85&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP + MTS</td>
<td>16.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.4&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.37&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>4.88&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV</td>
<td>17.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.3&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.25&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>0.96&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV + PEF</td>
<td>17.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.8&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.44&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>0.84&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV + MTS</td>
<td>16.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.8&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>3.57&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>4.44&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>p</sup> values calculated from the L, a and b replicate values.

<sup>ab</sup> Within columns, means not followed by the same superscript are significantly different (p < 0.05).

<sup>A</sup> ΔE values calculated from the L, a and b replicate values.

<sup>‡</sup> p < 0.05.

<sup>***</sup> p < 0.001.
found a 32.2% reduction of phenols in thermally-treated apple juice, while PEF processing (35 kV/cm, 4 μs, 1200 Hz) caused a 14.5% decrease. The total phenolics content of apple and cranberry juice in the present study did not significantly change after the application of any of the non-thermal treatments compared to the untreated control (Table 2). Similarly, the relative TEAC of apple and cranberry juice, shown in Table 2, was not affected by the non-thermal processes, whether applied as stand-alone hurdles or in combination, since the antioxidant activity in apples can be mostly attributed to their polyphenolic compounds (Eberhardt, 2000). No previous study has reported the effect of combined non-thermal treatments on anthocyanin stability. The present work revealed that the most successful combination in retaining monomeric anthocyanins in apple and cranberry juice was HILP followed by PEF (Table 2). The anthocyanin content was significantly lower (p < 0.05) when the product was processed by the combinations HILP + MTS, UV + MTS and UV + PEF and the reduction ranged between 19% and 24%. These treatments induced a significant decrease (p < 0.05) in the anthocyanin content, which was similar to the thermally treated sample. In contrast, when the effect on anthocyanins was assessed after treatment with either UV or HILP as a first hurdle, no significant changes were observed compared to the untreated control. The percent of polymeric colour of all the non-thermally treated samples was not significantly different from the control (mean value 84%), and this is in agreement with the NEBI results reported previously.

3.2. Sensory analysis

Sensory quality (Table 3) is an important aspect to be considered when non-thermal technologies are applied for preservation purposes. Panellists did not perceive any significant difference in appearance, sweetness and acidity of the apple and cranberry juice blend processed by the selected hurdle combinations, when compared to a conventionally pasteurised sample. However, the odour and the flavour of the resultant juice were significantly changed by the non-thermal treatments. In particular, the treatments which included MTS as a hurdle had a significantly lower odour (p < 0.05) (5.5 versus 6.5) and flavour (p < 0.01) (4.7 versus 5.6) scores than the thermally treated product. By contrast, the juice processed by HILP + PEF or UV + PEF received a similar (p > 0.05) score to the control for both attributes. Evaluation of the overall acceptability revealed that the sample processed by the combination UV + PEF was the most preferred product (5.8), followed by the sample treated by HILP + PEF (5.7). However, when the combined non-thermal approach included MTS, the acceptability

### Table 2
Selected chemical attributes of apple and cranberry juice.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>NEBI&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Total phenolics (GAE&lt;sup&gt;b&lt;/sup&gt;) (mg/l)</th>
<th>Relative TEAC&lt;sup&gt;c&lt;/sup&gt; (%)</th>
<th>C3G&lt;sup&gt;d&lt;/sup&gt; (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL</td>
<td>0.075</td>
<td>612.0</td>
<td>~</td>
<td>11.36&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>PASTEURISED</td>
<td>0.072</td>
<td>593.4</td>
<td>91.6</td>
<td>9.70&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP</td>
<td>0.076</td>
<td>613.6</td>
<td>94.1</td>
<td>9.85&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP + PEF</td>
<td>0.078</td>
<td>608.8</td>
<td>93.7</td>
<td>10.01&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP + MTS</td>
<td>0.076</td>
<td>584.0</td>
<td>82.6</td>
<td>8.66</td>
</tr>
<tr>
<td>UV</td>
<td>0.076</td>
<td>612.0</td>
<td>95.4</td>
<td>9.92&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV + PEF</td>
<td>0.076</td>
<td>594.2</td>
<td>99.2</td>
<td>8.59</td>
</tr>
<tr>
<td>UV + MTS</td>
<td>0.074</td>
<td>578.9</td>
<td>89.5</td>
<td>9.20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> NEBI: non-enzymatic browning index.
<sup>b</sup> GA: gallic acid equivalent.
<sup>c</sup> TEAC: trolox equivalent antioxidant activity.
<sup>d</sup> C3G: cyanidin-3-glucoside.
<sup>p</sup> < 0.05; NS: not significant.

### Table 3
Sensory analysis of apple and cranberry juice.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Appearance</th>
<th>Odour</th>
<th>Flavour</th>
<th>Sweetness</th>
<th>Acidity</th>
<th>Overall Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>HILP + MTS</td>
<td>5.1</td>
<td>5.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.3</td>
<td>5.1</td>
<td>4.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>HILP + PEF</td>
<td>6.0</td>
<td>6.1&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>5.8</td>
<td>6.0</td>
<td>5.5</td>
<td>5.7&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>PASTEURISED</td>
<td>6.0</td>
<td>6.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.6</td>
<td>5.8</td>
<td>5.5</td>
<td>5.4&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV + MTS</td>
<td>5.9</td>
<td>5.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.7</td>
<td>5.0</td>
<td>5.0</td>
<td>4.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>UV + PEF</td>
<td>5.9</td>
<td>6.2&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>5.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.4</td>
<td>5.7</td>
<td>5.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>p-Value</td>
<td>NS</td>
<td>~</td>
<td>~</td>
<td>NS</td>
<td>NS</td>
<td>~</td>
</tr>
<tr>
<td>SED</td>
<td>0.43</td>
<td>0.35</td>
<td>0.43</td>
<td>0.43</td>
<td>0.41</td>
<td>0.41</td>
</tr>
</tbody>
</table>

<sup>a</sup> HILP: High Intensity Light Pulses; PEF: Pulsed Electric Fields; MTS: Manothermosonication; UV: Ultraviolet; SED: Standard Error of Difference between treatment means.
<sup>b</sup> p < 0.05.
<sup>c</sup> p < 0.01; NS: Not Significant.
decreased significantly ($p < 0.05$), highlighting the unfavourable impact of this technology under the conditions applied. The thermally processed sample did not differ significantly ($p \geq 0.05$) in terms of the overall acceptability (Table 3) from any of the selected hurdle combinations. In a previous study, Walkling-Ribeiro, Noci, Cronin, Lyng, and Morgan (2009) described the effect of combined thermosonication (TS) ($55^\circ$C, 10 min) and PEF (40 kV/cm, 100 µs) processing on the sensory attributes of orange juice, and found no significant difference in any attribute compared to a thermally-treated ($94^\circ$C, 26 s) orange juice. However, some panellists did detect a metallic flavour in the TS/PEF treated product. The off-flavour noticed in the apple and cranberry samples may have originated from changes induced by the free radicals produced during MTS (Vercet, Lopez, & Burgos, 1998), though the identification of such compounds was beyond the scope of this work.

4. Conclusions

A light-based technology (UV or HILP) in combination with PEF or MTS was applied to a blend of apple and cranberry juice. This work suggests that UV + PEF or HILP + PEF are promising hurdle preservation combinations for maintaining product quality, while combinations which included MTS, had an adverse effect on product quality under the conditions applied.

Acknowledgments

The authors would like to acknowledge the financial support of the Non-Commissioned Food Institutional Research Measure, funded by the Department of Agriculture, Fisheries and Food, Ireland and the technical support provided by Keeling Fresh Juices Ltd., Ireland.

References


Odrizola-Serrano, I., Soliva-Fortuny, R., & Martin-Belloso, O. (2009). Impact of high-intensity pulsed electric fields variables on vitamin C, anthocyanins and antioxidant capacity of strawberry juice. *LWT – Food Science and Technology, 42*(1), 93–100.


