Antioxidants: an excellent phytochemical functional food from sugarcane

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Abstract

Oxygen Radical Absorbance Capacity (ORAC) antioxidant analysis of a number of sugarcane-derived samples confirmed significant antioxidant properties. The antioxidant capacity is proportional to the color of the products. This supports the previous findings that the antioxidant properties come at least in part from sugarcane plant phenolics of which in particular ferulic, syringic, p-coumaric and vanillic acids are known components. Non-zero final fluorescence observed in all samples in the ORAC analysis introduces an ambiguity that will need to be clarified and corrected for truly quantitative measure of antioxidant capacity of the sugarcane products. A process has been tested that is based on retention of the active components on non-ionic adsorbents, their desorption and regeneration of the adsorbent with dilute sodium hydroxide, and their recovery in concentrated form from the sodium hydroxide regenerant with a strong acid cation resin in hydrogen form. The yield of the active components was estimated as 4 grams per liter resin per cycle. The antioxidant capacity of the final purified product was found to be about 1,000,000 \( \mu \text{mole TE/100 g dry solids} \). This antioxidant capacity is comparable to the reported values for the pure phenolic acids. Fortification of food products in general and those produced by the sugar industry specifically with sugarcane derived antioxidants is proposed as a way to broaden the market reach for sugar products within the increasingly health-conscious population, similar as organic and specialty sugars have done.

Introduction

The role of dietary antioxidants in protecting tissues and cells against harmful effects of free radicals has been widely publicized (Weller, 1999), and numerous products extracted from natural sources are available as dietary supplements (Prior and Cao, 1999). A purified extract of bilberry, for example, rich in anthocyanins, was found to be effective in human subjects for reducing the clinical symptoms of lowered capillary resistance and increased retinal sensitivity. Extracts of strawberry and spinach were found to enhance the age-related functions of brain in rats, while blueberry extracts reduced the lung damage in rats subjected to pure oxygen. Extracts of green tea, Gingko
biloba, grape seed and many others, and their therapeutic effects, are well known. The market in the U.S. for antioxidant rich supplements and fortified drinks and snacks has now advanced well into the mainstream, with products such as green tea antioxidant enriched drinks (Fuze Beverage), health bars, powder drink mixes, etc. Not unexpectedly, some of the labelling is confusing and even misleading, but efforts at collaboration and standardization within the industry are underway (Bank, 2005; Nichols, 2005). An ACS symposium (2nd International Congress on Antioxidant Methods) in June, 2005 in Orlando was dedicated to review antioxidant testing procedures and promote efforts to unify the research and industry.

Sugarcane blackstrap molasses has long been claimed to have therapeutic properties. After the disclosure by Shin Mitsui Sugar workers and their collaborators at the 60th meeting of SIT of the physiological effects of sugar cane extracts, viz. promotion of resistance against viral and bacterial infections, stimulation of immune response, protection against liver injuries and growth promotion in chickens, but with no detail about a recovery process, tests were undertaken at Audubon Sugar Institute to establish basic elements of a realistic recovery process and confirm the antioxidant properties of the products. The results were encouraging (Saska and Chou, 2002) and were complemented the same year by a more detailed account by the Japanese researchers at the 61st SIT (Koge et al., 2002) of the beneficial physiological functions of these extracts. In a project “Antioxidantes Naturais” funded by the Portuguese government, the group at the Universidade Catolica in Oporto (Giao et al, 2002; Guimaraes, 2005) fractionated refinery effluents and dilute cane molasses on anion exchange resins. Two fractions eluted from a Levatit strong base anion resin respectively with 18 g/L and 41 g/L NaCl were found to have antioxidant properties as determined by ABTS (2,2’-azinobis-3-ethylbenzothiazoline-6-sulfonic acid) and deoxyribose essays. HPLC analysis revealed syringic, in fraction A and p-hydroxybenzoic, vanillic and ferulic acids in extract B to be the main phenolic compounds, presumably responsible for the antioxidant properties. Separation from the excess of NaCl was done with a 300Da nanofiltration membrane. These phenolic compounds are well known for their antioxidant properties (Table I) and their levels in sugarcane juice have been reported to be in the 0.2 – 11 mg/L range (Curtin and Paton, 1980; van der Poel et al, 1998). Colorless in their fee state, they form colored complexes or conjugates in sugarcane juice.

**Oxygen Radical Absorbance Capacity (ORAC) Analysis**

Cao et al. (1993,1995) introduced ORAC as a quantitative method of measuring the antioxidant activity of fruits, vegetables, food products, blood serum and natural extracts. With some variations the method has since then become widespread if not standard, adopted by researchers and the health foods and health supplement industries (Bank, 2005). ORAC values, in mole equivalents of trolox, a water soluble compound related to vitamin E per liter, gram of sample or gram dry solids are available in the literature for a number of common fruits, vegetables and antioxidant-rich food supplements. A few selected fruits and vegetables are listed in Table II for illustration. According to USDA research (Bank, 2005), ORAC value of an average serving of vegetables equals approximately 900 µmoles TE, ORAC value of an average serving of
fruit is approximately 3400 μmoles TE and the estimated ORAC intake of the daily recommended nine servings of fruits and vegetables equals about 20,000 μmoles TE.

The basis of the analysis is a competitive reaction between three principal components: a) the free radicals (most often peroxyl in ORAC techniques), b) an indicator, a fluorescent molecule which is the target of the free-radical attack, and c) the sample that is being tested for its protective antioxidants capacity. The indicator is chosen such that its reaction rate with the *in-situ* generated free-radicals is much slower than the reaction rate of the free radicals with most biological antioxidants. As the reaction proceeds between the indicator and the free radicals, the indicator molecule loses its fluorescence. Therefore, the lag of the fluorescence decay curve (Figure 1) with respect to a blank curve (no sample present) is proportional to the antioxidant, protective power of the sample. To quantify this effect, the areas $S$ under the decay curves are evaluated and the ORAC value is calculated as

$$\text{ORAC} = k \left( S_{\text{sample}} - S_{\text{blank}} \right) / \left( S_{\text{Trolox}} - S_{\text{Blank}} \right)$$

where the constant $k$ accounts for sample dilution. $S_{\text{sample}}$ and $S_{\text{blank}}$ are the areas under the sample and blank decay curves, respectively (Figure 1), and $S_{\text{trolox}}$ is the area under the curve where instead of the sample a known quantity was added of the well defined synthetic antioxidant, trolox (6-hydroxy-2,5,7,8-tetramethyl-2-carboxylic acid). A refinement of the technique (www.genox.com) has been the differentiation (Figure 1) between “fast” and “slow” antioxidant capacity, obtained from the integrals of the fluorescence curves ($S_{\text{sample}}$ and $S_{\text{blank}}$ terms in the numerator of the equation above) evaluated between the time zero and the time when the signal drops to 95% and 50% of the initial value, respectively. The total antioxidant activity of the sample is calculated by integration of the signal from the time zero until the end of the collection period when the signal is assumed to have reached zero. Unfortunately, it was found that this was not the case for our sugar-based samples and this is discussed in more detail later. All the ORAC analyses reported in this work were performed in Genox Corporation’s lab in Baltimore that uses as an indicator β-phycoerythrin, a natural protein extracted from white alga and AAPH (2,2′-azobis-2-amindinopropane dihydrochloride) as the *in-situ* generator of peroxyl radicals. Many other free radicals of biological or clinical interest have been described in the literature and employed in antioxidant essays, e.g. hydroxyl, ATBS, Cu$^{++}$, etc. The susceptibility of biological antioxidants to different free radicals and therefore the absolute values obtained with different radicals for the same sample vary widely (Prior, 2005). More recently, fluorescein has been used by some instead of β-phycoerythrin and ORAC values thus obtained are reported as ORAC$_{FL}$ (Table II). Another modification of the procedure has been introduced by Wu et al (2004) to allow differentiation between hydrophylic (H-ORAC$_{FL}$) and lipophilic (L-ORAC$_{FL}$) antioxidants. Comparison in Table II between ORAC and H-ORAC$_{FL}$ values for several fruits and vegetables is obviously affected not only by the differences in analytical techniques but also by the very large geographical and seasonal variability of the produce. Generally, little or no correlation has been seen among the various antioxidant essay (Prior, 2005; Jimenez-Eskrig et al, 2005).
One of the advantages of ORAC procedure is that it can be highly automated allowing unattended analysis of hundreds of samples. The raw data is integrated and processed with no intervention from the operator, and only the final ORAC values are usually reported to the clients. Only recently, when raw data were requested and inspected (fluorescence decay curves) it became apparent that the fluorescence curves apparently in all our samples did not reach the baseline, but rather leveled off within the 40 to 50 min over which the data were collected (e.g. the dilute molasses sample curve - triangles - in Figure 1). The slope of the curve is zero or almost zero at the end of the data collection so it does not appear that it is merely a matter of extending the collection time, nor does it appear that the inherent fluorescence of sugar impurities is responsible, as this residual is not at all proportional to the expected level of impurities in the samples, e.g. in the curves 9 and 15 in Figure 7 and Table IV for blackstrap molasses and refined sugar, respectively.

In the 2002 paper (Saska and Chou, 2002), five edible molasses (Table III) available on the U.S. market were characterized in terms of their composition and antioxidant properties. The first four are sugarcane-based products, the last one is corn-based with a small amount of a sugarcane liquor blended in for color. The antioxidant capacity of the five products was found to correlate well with their color (Figure 2). With some variations, the fast and slow ORAC values are lower than the total ORAC. This was interpreted as an indication that a part of the antioxidant capacity was from compounds with slow-acting functionality. Glucose was reported in the literature as having slow-acting antioxidant functionality and it was found to increase the apparent ORAC value of foods (Jimenez-Escrig et al, 2005). It is possible that glucose and in particular sucrose add to the overall apparent antioxidant capacity of the sugar-based products.

**Process for antioxidant recovery from sugarcane syrup**

The process based on a two-column system has been tested for recovery and purification of antioxidant compounds from sugarcane syrup. Elements of the process are subject of a published U.S. Patent application (Chou, 2003). In view of the recent results, it is apparent that some other feed streams could be used, eg. clarified juice, intermediate or final molasses or even some refinery liquors, provided they are sufficiently low in suspended solids to prevent premature fouling of the resins. With syrup, standard syrup clarification process followed with safety filtration should be sufficient, although much longer trials need to be undertaken to test the lifetime of the resins in the extended application. The first, adsorbent column, is packed with a non-ionic polymeric adsorbent that can be efficiently regenerated with dilute sodium hydroxide. Among some of the adsorbents tested so far have been XAD 1180 (Rohm and Haas Company, Philadelphia, PA), Tulsion ADS 600 and 700 (Thermax, Novi, MI and Pune, India) and SD300 (Hangzhou Zheng Guang Resin Company, PRC). The second column is packed with a strong acid cation exchange (SAC) resin in hydrogen form. Several SAC resins have been tested, eg. Rohm and Haas IR 200, Purolite C-150 and Thermax Tulsion T-42. In the first step (Figure 3) the adsorbent is loaded by passing the syrup through the adsorbent, preferably up-flow if concentrated syrup is used of a higher specific gravity than that of the adsorbent resin. Depending on the composition, some two to four bed volumes of the
feed are needed to nearly saturate the resin. The antioxidant depleted and partially
decolorized syrup is either returned back in the process or used for specialty sugars
boiling. The $10-30/L cost of the adsorbent resins appears to preclude large scale
application where the full volume of syrup or any other stream in a typical sugar factory
would be handled, but a smaller slip-stream of a partially decolorized syrup could be
used to produce direct white or other specialty products. In the second step, the
adsorbent column is sweetened off and prepared for antioxidant recovery in Step 3. A 1-
2% dilute hot sodium hydroxide solution is used to strip the active compounds of the
adsorbent column, and is neutralized in a downstream SAC column packed with a strong
acid cation exchange resin in H⁺ form. The adsorption of the active compounds on the
SAC resin is minimal and a 0.3 to 0.6 Brix de-ashed solution of the antioxidant product
is sent to be concentrated by reverse osmosis, evaporation and/or spray drying. In the last
step of the process, the adsorbent resin is washed off the regenerant with water. The SAC
column is first regenerated with dilute hydrochloric acid and then washed off with water.
The system is then ready for another production cycle. Obviously the process lends itself
to application of continuous adsorption and ion-exchange processes in order to
minimize adsorbent inventory and water use.

For preparative purposes, glass columns of 10-50 L of effective resin volume
have been used until now (Figure 4). The dilute spent regenerant exiting the SAC column
in Step 3 is acidic, with 3-5g/L dissolved solids. It was concentrated by boiling under
vacuum to 50g/L and sent for antioxidant testing without any further purification. The
overall yield is estimated at 4g dry solids/L resin/cycle. In order to test the longer-term
behavior of various adsorption resins, an automated system was set up at ASI (Figure 5)
for automated loading-washing-regeneration cycling on resins or adsorbents. Standard
laboratory peristaltic pumps, one each for feed, regenerant, and water, respectively are
switched on and off with a four-channel electronic timer, and a synchronized system of
solenoids - controlled by another timer - directs the flows - up or down the column - into
the appropriate collection bottles kept in a cooler to prevent spoilage in the extended
unattended tests. An example of repeated cycling on three adsorbents is illustrated in
Figure 6. In addition to the two polymeric adsorbents, Calgon CAL 12x40 granular
activated carbon was used for comparison. At some $1/L GAC could be a cost-effective
alternative to the more expensive polymeric adsorbents. For all three sorbents, the
conditions in Figure 6 were as follows:

Column: 2.5 x 60 cm at 75°C
Feed: sugarcane syrup, 55 Brix, Color 13,490 IU, heated, degassed and screened with a
50µm screen
Feed flow rate: 0.36 L/hr, 1.2 BV/hr
Regeneration and wash flow rate: 0.8 L/hr, 2.8 BV/hr

The total duration of each cycle was 3 hours: 1 hour of feeding syrup (Step 1 in Figure 3),
1/2 hour of sweetening off (Step 2), 1 hour regenerating with 1% NaOH (Step 3) and 1/2
hour washing (Step 4). In each case, decolorization gets progressively reduced, and becomes nil
on GAC after about 50 regeneration cycles. The regeneration conditions are by no means
optimized, and it is very likely that a periodic acid wash and higher temperature during
regeneration would improve regeneration efficiency, but the comparison at identical conditions is
nevertheless useful for adsorbent selection. The operation and capacity of the SAC resin is related to the concentration of the sodium hydroxide regenerant, and in line with the standard operating procedures supplied by the resin manufacturers.

**Antioxidant properties of sugar cane derived products**

The samples of antioxidant-rich products, samples of the feed syrup, and a number of other samples of interest were sent for ORAC analysis at Genox Corporation. All those for which the raw fluorescence v. time data are available are presented in Figure 7 and Table IV. In addition to samples generated at Audubon Sugar Institute, several retail products - sugars and molasses - were also sent for the analysis to complement the tests done in 2002 and summarized in Table III. Obviously, enriching sugar or edible molasses with the sugarcane antioxidants is one of its potential applications, therefore the antioxidant properties of the various commercial products are of interest. The data in Table IV are separated according to the four sets by the date the analysis was done and according to the sample number that corresponds to the curve numbers in Figure 7. The samples were shipped to Genox frozen at the concentration (Brix) given in the table that had been adjusted close to 5 in order to minimize the effects of dilution on ORAC analysis. Samples 1 to 15 were further diluted 1:10 at Genox before analysis, while the samples 16 to 22 were analyzed as received. The fast and slow ORAC results are given in Table IV as reported by Genox, in µmole TE/100 g sample as analyzed and should therefore be multiplied by 1000/Brix for samples 1 to 15 and by 100/Brix for samples 16 to 22 in order to convert the ORAC values to µmole TE/100 g dry solids.

CLM, cane leaf matter juice (samples 5,6,7) is the juice pressed from green leaves and tops of sugarcane (Gil, 2006). CLM juice stillage is the liquid residue after sucrose and invert sugars in CLM juice had been fermented to ethanol and ethanol removed by distillation. AOX-depleted syrup (samples 11-13) is the partially decolorized syrup exiting the adsorption column during Step 1 of the recovery process. These samples were collected and analyzed in order to provide mass-balance of the antioxidants around the adsorption column. Color (420 nm, pH 7.0, 0.45 µm filtration) was determined in most of the samples.

Clearly, the results of the set of 2/25/2005 are substantially higher and not comparable with the others sets, although apparently consistent within the set in the sense that the lowest ORAC values are for refined sugar, and the antioxidant (AOX) product has by far the highest ORAC value. The other three sets appear more consistent, and both fast and slow ORAC values fit the expected trends, e.g. lowest values for refined and raw sugar samples. The reported ORAC numbers for the decolorized syrup samples 11-13 do not show the expected pattern, but indicate rather more or less same fast and slow ORAC values as the feed syrup. Detailed inspection of the fluorescence curves from this set (Figures 10 - 14) though clearly confirms the expected pattern and reveals the inadequacy in some cases of the overall reported ORAC values. The vertical separation between the blank and the sample curves at the very short time < 2 min is proportional to fast ORAC. For the feed syrup (Figure 8) the separation between the two curves is obvious, for the first decolorized fraction (Figure 9) it is nil, it is slightly larger for the second fraction (Figure 10) and comparable if not somewhat larger in fraction 3 (Figure 11) than in the
feed syrup. The true “fast” antioxidant levels do therefore correctly reflect the expected behavior (i.e. lowest levels in the first-eluting fraction from the adsorption column) and are clearly proportional to the color of the three fractions. The problem is obviously with the precision or reliability of the automatic integration of the fluorescence signals for very low-antioxidant samples.

One of the objectives of the program was evaluation of the antioxidant capacity of the retail sugar products and their comparison with the ORAC values for fruits and vegetables reported in the literature. The comparison is made difficult by the limited precision and repeatability of the ORAC analysis in inter-laboratory studies, and the yet unexplained problems with non-zero baseline seen in all our samples. The reported fast and slow ORAC of brown sugars (samples 16 to 18) of 47 and about 70 respectively, translate to about 940 and 1,400 µmole TE/100 g and that is comparable to ORAC of the lower antioxidant produce, watermelon and celery reported in Table II. Of the four liquid sweeteners (samples 19 -22), as expected the corn syrup is lowest in ORAC. The correlation particularly between the slow ORAC and the color of the molasses is very good, similar as was found in 2002. The comparison between the identical products (Karo Corn Syrup, Grandma’s Molasses and Brer Rabbit Molasses) purchased and analyzed in 2002 and then again in April 2006 is not unreasonable realizing the changes in the laboratory protocol that may have occurred in the meantime, and the intricacies of the analysis proper that were revealed in this program.

References


Giao M.S., Bento, L.S., Genisheva Z.A., Pintado M.E., Gomes A. P. and Malcata F.X. Total antioxidant activities associated with products from the sugar industry (poster), December 2002


Nichols J., Industry needs and issues related to antioxidant measurement. Proc. 2nd International Congress on Antioxidant Methods, June 22-24, 2005, Orlando, FL


Table I: Antioxidant properties of various phenolic acids, known components of sugarcane juice, in µ mole TE/100 g (Prior and Cao, 1999).

<table>
<thead>
<tr>
<th>Phenolic Acid</th>
<th>ORAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>caffeic acid</td>
<td>1,238,000</td>
</tr>
<tr>
<td>ferulic acid</td>
<td>685,000</td>
</tr>
<tr>
<td>gallic acid</td>
<td>1,023,000</td>
</tr>
<tr>
<td>p-coumaric acid</td>
<td>1,337,000</td>
</tr>
<tr>
<td>syringic acid</td>
<td>641,000</td>
</tr>
<tr>
<td>vanillic acid</td>
<td>660,000</td>
</tr>
</tbody>
</table>

Table II: Antioxidant properties of various high-antioxidant fruits and vegetables in µ mole TE/100 g dry solids. ORAC from Cao et al (1996) and Wang et al (1996), H-ORAC<sub>FL</sub> from Wu et al, 2004.

<table>
<thead>
<tr>
<th>Fruit</th>
<th>ORAC</th>
<th>H-ORAC&lt;sub&gt;FL&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watermelon</td>
<td>1,300</td>
<td>1,450</td>
</tr>
<tr>
<td>Plum</td>
<td>7,900</td>
<td>47,400</td>
</tr>
<tr>
<td>Strawberry</td>
<td>15,400</td>
<td>37,200</td>
</tr>
<tr>
<td>Orange</td>
<td>5,200</td>
<td>12,000</td>
</tr>
<tr>
<td>Lettuce, iceberg</td>
<td>3,900</td>
<td>9,800</td>
</tr>
<tr>
<td>Celery</td>
<td>1,300</td>
<td>10,700</td>
</tr>
<tr>
<td>Broccoli</td>
<td>5,900</td>
<td>14,900</td>
</tr>
</tbody>
</table>

Table III: Composition of the five edible molasses products in g/100 g. ORAC in µ mole TE/100 g dry solids.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sucrose</th>
<th>Glucose</th>
<th>Fructose</th>
<th>Ash</th>
<th>Color IU</th>
<th>Fast ORAC</th>
<th>Slow ORAC</th>
<th>Total ORAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steen's Home Style Molasses</td>
<td>33</td>
<td>18</td>
<td>17</td>
<td>3.4</td>
<td>38,300</td>
<td>1,170</td>
<td>1,840</td>
<td>4,440</td>
</tr>
<tr>
<td>Wholesome Foods Organic Blackstrap</td>
<td>35</td>
<td>8</td>
<td>10</td>
<td>5.8</td>
<td>186,800</td>
<td>6,430</td>
<td>8,860</td>
<td>11,370</td>
</tr>
<tr>
<td>Mott's Grandma's Molasses</td>
<td>30</td>
<td>18</td>
<td>17</td>
<td>3.1</td>
<td>69,000</td>
<td>1,700</td>
<td>2,660</td>
<td>5,340</td>
</tr>
<tr>
<td>B&amp;G Foods Brer Rabbit</td>
<td>30</td>
<td>16</td>
<td>18</td>
<td>4.6</td>
<td>89,400</td>
<td>2,640</td>
<td>3,740</td>
<td>6,180</td>
</tr>
<tr>
<td>Karo Dark Corn with Refiners' Syrup</td>
<td>2</td>
<td>14</td>
<td>1</td>
<td>0.68</td>
<td>4,000</td>
<td>160</td>
<td>260</td>
<td>2,830</td>
</tr>
</tbody>
</table>
Table IV: ORAC analysis of various sugarcane-based products. Curve numbers correspond to Figure 7. Fast ORAC and slow ORAC are the values in \( \text{mole TE/100 g} \) diluted sample as reported by Genox Corporation. The samples were shipped frozen at the concentration (Brix) given in the table but diluted 1:10 before analysis (curves 1 – 15) or analyzed as delivered (curves 16 – 22). AOX = antioxidant. CLM = cane leaf matter. NA = not analyzed.
<table>
<thead>
<tr>
<th>Curve No.</th>
<th>Set</th>
<th>Sample description</th>
<th>Brix</th>
<th>Color</th>
<th>Fast ORAC</th>
<th>Slow ORAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/25/2005</td>
<td>refined sugar</td>
<td>5.1</td>
<td>NA</td>
<td>338</td>
<td>1,111</td>
</tr>
<tr>
<td>2</td>
<td>-“-</td>
<td>sugarcane syrup</td>
<td>5.3</td>
<td>11,500</td>
<td>361</td>
<td>1,549</td>
</tr>
<tr>
<td>3</td>
<td>-“-</td>
<td>AOX product</td>
<td>4.9</td>
<td>NA</td>
<td>&gt;2,000</td>
<td>&gt;5,000</td>
</tr>
<tr>
<td>4</td>
<td>5/12/2005</td>
<td>CLM juice stillage</td>
<td>5.1</td>
<td>NA</td>
<td>268</td>
<td>1,551</td>
</tr>
<tr>
<td>5</td>
<td>-“-</td>
<td>CLM juice</td>
<td>4.1</td>
<td>213,000</td>
<td>88</td>
<td>1,278</td>
</tr>
<tr>
<td>6</td>
<td>-“-</td>
<td>CLM juice</td>
<td>5.1</td>
<td>127,000</td>
<td>79</td>
<td>2,137</td>
</tr>
<tr>
<td>7</td>
<td>-“-</td>
<td>CLM juice</td>
<td>5.0</td>
<td>112,000</td>
<td>53</td>
<td>1,157</td>
</tr>
<tr>
<td>8</td>
<td>-“-</td>
<td>chlorophyl from CLM juice</td>
<td>NA</td>
<td>NA</td>
<td>36</td>
<td>735</td>
</tr>
<tr>
<td>9</td>
<td>10/5/2005</td>
<td>sugarcane blackstrap molasses</td>
<td>5.3</td>
<td>NA</td>
<td>67</td>
<td>1,827</td>
</tr>
<tr>
<td>10</td>
<td>-“-</td>
<td>sugarcane syrup</td>
<td>5.5</td>
<td>11,150</td>
<td>37</td>
<td>1,645</td>
</tr>
<tr>
<td>11</td>
<td>-“-</td>
<td>AOX-depleted syrup, F1</td>
<td>3.8</td>
<td>1,630</td>
<td>36</td>
<td>2,098</td>
</tr>
<tr>
<td>12</td>
<td>-“-</td>
<td>AOX-depleted syrup, F2</td>
<td>4.8</td>
<td>3,180</td>
<td>36</td>
<td>1,287</td>
</tr>
<tr>
<td>13</td>
<td>-“-</td>
<td>AOX-depleted syrup, F3</td>
<td>4.5</td>
<td>13,160</td>
<td>39</td>
<td>1,608</td>
</tr>
<tr>
<td>14</td>
<td>-“-</td>
<td>AOX product</td>
<td>4.5</td>
<td>NA</td>
<td>182</td>
<td>3,168</td>
</tr>
<tr>
<td>15</td>
<td>-“-</td>
<td>refined sugar</td>
<td>5.3</td>
<td>NA</td>
<td>36</td>
<td>1,663</td>
</tr>
<tr>
<td>16</td>
<td>4/18/2006</td>
<td>Domino Dark Brown Sugar</td>
<td>5.1</td>
<td>7,970</td>
<td>48</td>
<td>86</td>
</tr>
<tr>
<td>17</td>
<td>-“-</td>
<td>Sugar in The Raw (Maui)</td>
<td>5.1</td>
<td>1,530</td>
<td>47</td>
<td>65</td>
</tr>
<tr>
<td>18</td>
<td>-“-</td>
<td>Florida Crystals Demerara Sugar (Mauritius)</td>
<td>5.3</td>
<td>2,710</td>
<td>47</td>
<td>70</td>
</tr>
<tr>
<td>19</td>
<td>-“-</td>
<td>Karo Dark Corn Syrup</td>
<td>5.2</td>
<td>4,550</td>
<td>47</td>
<td>65</td>
</tr>
<tr>
<td>20</td>
<td>-“-</td>
<td>Brer Rabbit Molasses</td>
<td>5.0</td>
<td>94,500</td>
<td>72</td>
<td>1,237</td>
</tr>
<tr>
<td>21</td>
<td>-“-</td>
<td>Grandma’s Molasses</td>
<td>5.1</td>
<td>60,100</td>
<td>79</td>
<td>617</td>
</tr>
<tr>
<td>22</td>
<td>-“-</td>
<td>Steen’s 100% Pure Cane Syrup</td>
<td>4.9</td>
<td>11,120</td>
<td>75</td>
<td>179</td>
</tr>
</tbody>
</table>
Figure 1: Fluorescence signal v. time of a) blank, i.e., no antioxidant present (diamonds), b) blackstrap molasses solution, curve No. 9 from Table IV and Figure 7 (triangles) and c) standard (squares), 1.3 µM solution of trolox. The ORAC values (fast, slow and total) are calculated from the areas under the three respective curves.
Figure 2: Antioxidant capacity of five retail edible molasses products in ‚mole TE/100 g dry solids as a function of their color. Data from Saska and Chou (2002) and Table III.
Figure 3: Process for recovery of antioxidant compounds from sugarcane syrup. ADS = adsorbent column, SAC = strong acid anion column.

Figure 4: The 50L preparative columns used for antioxidant recovery tests.
Figure 5: The automated resin testing apparatus.
Figure 6: Decolorization of sugarcane syrup with three adsorbents, over a number of regeneration cycles.

Figure 7: Fluorescence v. time raw data for four sets of data. Curve numbers correspond to the symbols in Table IV.
Figure 8: ORAC analysis of sugarcane syrup. Curve 10 in Table IV and Figure 7.
Figure 9: ORAC analysis of effluent fraction 1. Curve 11 in Table IV and Figure 7. Symbols as in Figure 1.
Figure 10: ORAC analysis of effluent fraction 2. Curve 12 in Table IV and Figure 7. Symbols as in Figure 1.
Figure 11 ORAC analysis of effluent fraction 3. Curve 13 in Table IV and Figure 7. Symbols as in Figure 1.
Figure 12: ORAC analysis of antioxidant product. Curve 14 in Table IV and Figure 7. Symbols as in Figure 1.
Figure 13: ORAC analysis of refined sugar. Curve 15 in Table IV and Figure 7. Symbols as in Figure 1.