Current Research

Total Antioxidant Content of Alternatives to Refined Sugar

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ABSTRACT

Background Oxidative damage is implicated in the etiology of cancer, cardiovascular disease, and other degenerative disorders. Recent nutritional research has focused on the antioxidant potential of foods, while current dietary recommendations are to increase the intake of antioxidant-rich foods rather than supplement specific nutrients. Many alternatives to refined sugar are available, including raw cane sugar, plant saps/syrups (eg, maple syrup, agave nectar), molasses, honey, and fruit sugars (eg, date sugar). Unrefined sweeteners were hypothesized to contain higher levels of antioxidants, similar to the contrast between whole and refined grain products.

Objective To compare the total antioxidant content of natural sweeteners as alternatives to refined sugar.

Design The ferric-reducing ability of plasma (FRAP) assay was used to estimate total antioxidant capacity. Major brands of 12 types of sweeteners as well as refined white sugar and corn syrup were sampled from retail outlets in the United States.

Results Substantial differences in total antioxidant content of different sweeteners were found. Refined sugar, corn syrup, and agave nectar contained minimal antioxidant activity (<0.01 mmol FRAP/100 g); raw cane sugar had a higher FRAP (0.1 mmol/100 g). Dark and blackstrap molasses had the highest FRAP (4.6 to 4.9 mmol/100 g), while maple syrup, brown sugar, and honey showed intermediate antioxidant capacity (0.2 to 0.7 mmol FRAP/100 g). Based on an average intake of 130 g/day refined sugars and the antioxidant activity measured in typical diets, substituting alternative sweeteners could increase antioxidant intake an average of 2.6 mmol/day, similar to the amount found in a serving of berries or nuts.

Conclusion Many readily available alternatives to refined sugar offer the potential benefit of antioxidant activity.

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Oxidative damage has been implicated in the etiology of cancer, cardiovascular disease, and other degenerative disorders (1-3). Antioxidants are compounds with a reductive-oxidative potential and, therefore, have the ability to scavenge free radicals and other reactive oxygen species. Naturally occurring antioxidants in foods include vitamin E (tocopherols), vitamin C (ascorbic acid), flavonoids, lycopene, phenolic acids, and polyphenols, as well as some food additives (eg, butylated hydroxyanisole and butylated hydroxytoluene). Antioxidants prevent oxidative damage induced by free radicals and reactive oxygen species generated in vivo as byproducts of metabolism or inflammatory processes by suppressing their formation, acting as scavengers, or acting as their substrate.

The total antioxidant capacity (TAC) of diets has been correlated with increased concentration of specific antioxidants (eg, carotenoids, tocopherols, vitamin C) and foods (eg, coffee, wine, fruits) (4). Serafini and colleagues (5) observed an inverse relationship between dietary TAC and incidence of gastric cancer. Current dietary recommendations are to increase the intake of antioxidant-rich foods rather than supplement specific nutrients (6). While the interaction of specific antioxidants and other food nutrients as related to physiological effects remain to be completely determined, TAC is generally considered a valuable parameter for identifying potentially rich food sources of biologically active antioxidants that might have beneficial health effects. TAC is assayed by several methods, including ferric-reducing ability of plasma (FRAP) (7), oxygen radical absorbance capacity (ORAC) (8), Trolox-equivalent antioxidant capacity (9), 2,2′-azinobis (3-ethylbenzothiazoline 6-sulfonate) (10), and 2,2-diphenyl-1-picrylhydrazyl (11) radical scavenging assays.

The FRAP assay is a simple, fast, and inexpensive method for quantitative determination of the amounts of antioxidants in samples. The assay has little selectivity and measures most reductants above a certain reduction potential. The FRAP assay does not detect glutathione or protein thiols. This is an advantage over the ORAC and Trolox-equivalent antioxidant capacity assays because these thiols, which are present in high concentrations in animal and plant cells, are mainly degraded in the intestine and poorly absorbed. The original FRAP assay has a limited ability to measure fat-soluble antioxidants (7). Therefore, a modified FRAP assay was developed and reported previously (12) that also measures fat-soluble antioxidants. On the basis of these and other considerations (13), the FRAP assay was chosen for assessing TAC.

Some recommended dietary changes involve adding or increasing the intake of antioxidant-rich foods, such as berries, dark chocolate, nuts, green tea, and red wine (14-17). Refined sugar and corn syrup are the predominate sweeteners in Western diets. The estimated annual intake of added sugars in the United States (predominately from refined cane and beet sugar, corn syrup, glucose, and dextrose) is 47.5 kg per capita (31 tsp or 130 g per person per day) (18), yet sugar and refined corn syrup are virtually devoid of vitamins, minerals, and phytochemicals. Substitution of whole grains for refined flours and baked goods is recommended because whole grains are richer in antioxidants and nutrients lost in the refining process (19,20). It might be similarly expected that unrefined sweeteners derived from plants would also be richer in antioxidants, but little data exist on the composition of these products. Current attention to reducing refined sugar intake largely translates into replacement by artificial sweeteners (sucralose, aspartame, etc) with the purpose of reducing energy and carbohydrate intake, whereas natural whole-food alternatives represent a way to increase antioxidant and nutrient consumption.

Many alternatives to refined sugar are available, though not widely used. These include plant saps/syrups (eg, maple syrup, agave nectar), syrups made from raw sugar and grains (eg, molasses, barley malt, and brown rice syrup), honey, and fruit sugars (eg, date sugar), as well as raw cane sugar. It was hypothesized that some of these alternatives contain higher levels of antioxidants compared to refined white sugar. Blomhoff and colleagues (12,21,22) recently published values for the TAC of foods using the FRAP method. Results of the analysis of approximately 200 fruits, vegetables, spices and herbs, cereals, supplements, juices and drinks sampled mainly from European countries have been reported (21,22), and a table of the FRAP content of 1,113 US food samples was published recently (12). In the present study, additional results are reported for sweeteners, along with estimates of the impact on total antioxidant intake they could make if used as alternatives to refined sugar.

METHODS

Samples

Samples (Table 1) were procured locally and also through the United States Department of Agriculture's (USDA) National Food and Nutrient Analysis Program (NFNAP) between 2002 and 2006 for the analysis of other nutrients (23). NFNAP is designed to update and improve the food composition data in the USDA's National Nutrient Database for Standard Reference (24). Data for selected artificial sweeteners (eg, aspartame and sucralose) were reported previously (12) and found to contain FRAP <0.05 mmol/100 g; these products were not further considered in this study because the focus was on natural alternatives to refined white sugar that might be utilized by consumers.

The sampling design for NFNAP has been described previously (25). Local samples were procured from major retail outlets and/or health food stores or online distributors and represented major brands available in the US marketplace. Because the purpose of this study was to screen antioxidant content, a full statistical sampling plan was not implemented for all foods, although multiple samples of most products were obtained (see Table 1).

Samples were handled according to standardized, thoroughly documented procedures (26). When composites were prepared, each sample unit was mixed, if necessary, and a representative subsample of no less than 1 cup (240 mL) of liquids and 4 oz (113 g) solids was taken, then combined and stirred thoroughly. Subsamples were dispensed among 30-mL glass jars with Teflon-lined lids (Qorpak, Bridgeville, PA), sealed under nitrogen, and stored at -60 ± 5°C in darkness before analysis. Samples were shipped on dry ice via express air delivery from Blacksburg, VA to Oslo, Norway, received in frozen condition, and stored at -80°C prior to analysis. The range of storage time in Oslo was from 0 to 25 weeks prior to analysis.

Reagents

TPTZ (2,4,6-tri-pyridyl-s-triazine) was obtained from Fluka (Sigma-Aldrich, Deisenhofen, Switzerland), sodium acetate trihydrate and $FeSO_4 \times 7\ H_2O$ from Riedel-deHaën (Sigma-Aldrich, Germany), acetic acid and hydrochloric acid from Merck (Merck, Darmstadt, Germany), $FeCl_3 \times 6\ H_2O$ from BDH Laboratory Supplies (Poole, Dorset, UK). MilliQ water (Millipore, Bedford, MA) was used to ensure proper water quality. Methanol of high-performance liquid chromatography−grade was obtained from Merck.

FRAP Analysis

The antioxidant assay of Benzie and Strain (7) was used with minor modifications that allowed quantitation of most water- and fat-soluble antioxidants, as described previously (12). A Technicon RA 1000 system (Technicon Instruments Corporation, Tarrytown, NY) was used for the measurement of absorption changes that appear when the Fe^{3+}-TPTZ2 complex is reduced to the Fe^{2+}-TPTZ2 form in the presence of antioxidants. An intense blue color with absorption maximum at 593 nm develops. Measurements were performed at 600 nm after 4 minutes incubation. An aqueous solution of 500 μmol/L $FeSO_4 \times 7\ H_2O$ was used for calibration of the instrument. Three analytical portions of each sample were extracted, each extract was analyzed in triplicate, and results are given as reduced TPTZ-Fe^{2+}-complexes in mmol/100 g.

Quality Control

Stability of samples during storage was established in a previous study (12), where it was determined that different homogenized foods could be stored at -80°C for 65 weeks with only negligible changes in antioxidant content. The assay was also fully validated as described in a previous report (12). The within-day repeatability measured as relative standard deviation ranged from 0.4% to 6%. The variation in the values for replicate items obtained from the same source was typically between 3% and 10% relative standard deviation.

Table 1. Antioxidant capacity [ferric-reducing ability of plasma (FRAP)] of sweeteners

Product	NDB number[a]	Brand[b]	Composite type[c]	No. of sample units per composite	FRAP mean mmol/100 g	Standard error[d]	Serving size[e]	FRAP mmol/ serving	Product mean FRAP mmol/100 g	Product mean FRAP mmol/ serving
Honey	19296	Sue Bee	N	10	0.165	0.019	30 mL (1 Tbsp=21 g)	0.035	0.156	0.033
		Sue Bee	N	10	0.139			0.029		
		Store brand	N	10	0.154	0.003		0.032		
		Store brand	N	10	0.159			0.033		
		Multiple brands[f]	N	10	0.135			0.028		
		Dutch Gold	L	1	0.138*			0.029		
		Golden Blossom	L	1	0.193*			0.041		
		FMV	L	1	0.161*			0.034		
Corn syrup, light	19350	Karo	N	12	0.008*		30 mL (1 Tbsp=20 g)	0.002	0.006	0.0012
		Clement Foods Co	P	3	0.005	0.001		0.001		
		Clement Foods Co	P	3						
		Clement Foods Co	P	3						
Molasses, blackstrap	NA	Slow as Molasses	L	1	4.394[z]	0.018	30 mL (1 Tbsp=20 g)	0.879	4.894	0.979
		Plantation	L	1	4.776[y]	0.064		0.955		
		Brer Rabbit	L	1	5.513[x]	0.048		1.103		
Molasses, dark	NA	Grandma's	L	1	4.251	0.090	30 mL (1 Tbsp=20 g)	0.850	4.562	0.912
		Golding Farms	L	1	4.533	0.142		0.907		
		Brer Rabbit	L	1	4.900			0.980		
Maple syrup, 100% pure	19353	Private Selection	L	1	0.412	0.026	30 mL (1 Tbsp=20 g)	0.082	0.412	0.082
		Cary's	L	1	0.371	0.014		0.074		
		Spring Tree	L	1	0.454*			0.091		
Agave nectar, light	NA	Madhava	L	1	0.032	0.024	30 mL (1 Tbsp=21 g)	0.007	0.019	0.004
		Madhava	L	1	0.005	0.003		0.001		
Agave nectar, amber	NA	Madhava	L	1	0.031	0.003	30 mL (1 Tbsp=21 g)	0.006	0.031	0.0065
Agave nectar, raw	NA	Madhava	L	1	0.010	0.002	30 mL (1 Tbsp=21 g)	0.002	0.010	0.0021
Blue agave nectar	NA	Molino Real	L	1	0.034[z]	0.003	30 mL (1 Tbsp=21 g)	0.007	0.089	0.019
		Live Superfoods	L	1	0.143[y]	0.010		0.030		
Brown rice syrup	NA	Lundberg Family Farms	L	1	0.394[z]	0.042	30 mL (1 Tbsp=20 g)	0.079	0.200	0.040
		NOW Foods	L	1	0.006[y]	0.003		0.001		
Brown rice syrup, powdered		Emperor's Kitchen	L	1	1.041*	0.295	1 oz (28.35 g)	0.295	1.041	0.295
Brown rice malt syrup	NA	Sweet Cloud	L	1	0.717*		30 mL (1 Tbsp=20 g)	0.143	0.717	0.143
Barley malt syrup	NA	Eden Organic	L	1	1.008	0.166	30 mL (1 Tbsp=20 g)	0.202	1.565	0.313
	NA	Sweet Cloud	L	1	2.121*			0.424		
Sugar, granulated white	19335	Domino, C&H	R	3	0.009	0.002	1 oz (28.35 g)	0.002	0.009	0.003
		Domino, C&H	R	3	0.017	0.009		0.005		
		Store Brand	R	1	0.004	0.001		0.001		
		Store Brand	R	2	0.009	0.002		0.003		
		Kroger	L	1	0.004*			0.001		
Sugar, light brown	19334[g]	Domino, C&H, Dixie Crystals	N	10	0.385	0.018	1 oz (28.35 g)	0.109	0.361	0.102
		Store brand	N	7	0.337	0.015		0.096		

(continued)

Table 1. Antioxidant capacity [ferric-reducing ability of plasma (FRAP)] of sweeteners (continued)

Product	NDB number[a]	Brand[b]	Composite type[c]	No. of sample units per composite	FRAP mean mmol/100 g	Standard error[d]	Serving size[e]	FRAP mmol/ serving	Product mean FRAP mmol/100 g	Product mean FRAP mmol/ serving
Sugar, dark brown	19334[g]	Store brand	N	6	0.689	0.039	1 oz (28.35 g)	0.195	0.689	0.195
Sugar, turbinado	NA	Sugar in the Raw	R	3	0.079	0.019	1 oz (28.35 g)	0.022	0.126	0.036
		Sugar in the Raw	L	1	0.210*			0.059		
		Hain Pure Foods	R	3	0.090	0.013		0.026		
Sugar, raw cane	NA	Florida Crystals	L	1	0.165	0.017	1 oz (28.35 g)	0.047	0.204	0.058
		Wholesome Sweeteners	L	1	0.120	0.004		0.034		
		Sweet Cloud	L	1	0.327*			0.093		
Date sugar	NA	Bob's Red Mill	L	1	4.586[z]	0.020	1 oz (28.35 g)	1.300	3.273	0.928
		Barry Farm	L	1	2.996[y]	0.053		0.849		
		NOW Foods	L	1	2.237[x]	0.034		0.634		

[a]Entry reference number from US Department of Agriculture (USDA) Nutrient Database for Standard Reference (24). NA=not applicable (food not in database).

[b]Supplier information: Barry Farm (Wapakoneta, OH), Bob's Red Mill (Bob's Red Mill Natural Foods, Milwaukie, OR), Brer Rabbit (B&G Foods, Inc, Roseland, NJ), C&H (C&H Sugar Company, Inc, Crockett, CA), Cary's (Specialty Brands of America, Inc, Westbury, NY), Clements Foods Co (Oklahoma City, OK), Dixie Crystals (Imperial Sugar Company, Sugar Land, TX), Domino (Domino Foods, Inc, Yonkers, NY), Dutch Gold (Dutch Gold Honey, Inc, Lancaster, PA), Eden Organic (Eden Foods, Inc, Clinton, MI), Emperor's Kitchen (Great Eastern Sun, Asheville, NC), Florida Crystals (Florida Crystals Food Corp, West Palm Beach, FL), FMV (Inter-American Products, Inc, Cincinnati, OH), Golden Blossom (John Paton, Inc, Doylestown, PA), Golding Farms (Golding Farms Foods, Inc, Winston-Salem, NC), Grandma's (Mott's, Inc, Stamford, CT), Hain Pure Foods (The Hain Celestial Group, Inc, Boulder, CO), Karo (ACH Food Companies, Inc, Memphis, TN), Kroger (The Kroger Co, Cincinnati, OH), Live Superfoods (Bend, OR), Lundberg Family Farms (Richvale, CA), Madhava (Madhava Honey, Lyons, CO), Molino Real (Dictor S.A. de C.V., Guadalajara, Jalisco, Mexico), NOW Foods (Bloomingdale, IL), Plantation (Allied Old English, Inc., Port Reading, NJ), Private Selection (Inter-American Products, Inc, Cincinnati, OH), Slow as Molasses (Honeytree, Inc, Onsted, MI), Spring Tree (Spring Tree Maple Products, Westbury, NY), Sue Bee (Sue Bee Honey, Sioux City, IA), Sugar in the Raw (Cumberland Packing Corp, Brooklyn, NY), Sweet Cloud (Great Eastern Sun, Asheville, NC), Wholesome Sweeteners (Wholesome Sweeteners, Inc, Sugar Land, TX).

[c]N=national composite of samples; R=regional composite of samples (25); L=sample(s) from a single outlet; P=commodity product provided by directly by producer.

[d]Standard error, based on values from analysis of replicate subsamples.

[e]Based on product label and/or US Department of Agriculture Nutrient Database for Standard Reference (24).

[f]Composite of seven brands (ie, Madhava Mountain, Deep South, Barkmans Busy Bee, Billy Bee, Stollers, Winnie the Pooh, and Beemaid).

[g]"Sugars, brown."

[xyz]Means with different superscript letter (x,y,z), within data for that product, were significantly different for n=3 analytical replicates (α=.05); samples assayed with n=1 are marked with *.

Serving Sizes and Sweetening Equivalents

Weight and serving size of a typically consumed portion of each food was determined from the USDA National Nutrient Database for Standard Reference (24) and/or the product label, generally based on the US Food and Drug Association Nutrition Labeling and Education Act guidelines (27), or actual measurement of average portion weights taken during sample preparation.

Statistical Methods

Means, standard deviations, and standard errors were calculated using Microsoft Excel 2000 (version 9.0, Microsoft Corp, Redmond, WA). Data were subjected to an analysis of variance and Tukey test for multiple comparisons, with $\alpha=0.05$, using SAS (version 8.2 [TS2M0], 2001, SAS Institute, Cary, NC).

RESULTS

Antioxidant Content of Sweeteners

Table 1 summarizes the FRAP content of the individual samples, and the means for each product type. Refined white sugar and corn syrup had FRAP <0.01 mmol/100 g, while raw cane sugar had 0.2 to 0.3 mmol/100 g. Brown sugar was notably higher in antioxidant content relative to refined white sugar, with dark brown averaging nearly twice that of light brown (0.69 vs 0.36 mmol/100 g). Molasses (blackstrap and dark) was richest in antioxidant capacity of all products (4.89 and 4.56 mmol/100 g, respectively), followed by malt syrups (brown rice and barley) with FRAP of about 1 to 1.5 mmol/100 g. Maple syrup had FRAP of 0.41 mmol/100 g), while the antioxidant content of honey was similar to that of raw cane sugar. All types of agave nectar had low FRAP, similar to refined white sugar and corn syrup. In cases where multiple brands of a given sweetener were sampled and analyzed in replicate, there were no large statistically significant differences in antioxidant content except among blackstrap molasses, date sugar, brown rice syrup, and blue agave nectar products (although all samples of the latter contained a relatively low level of antioxidant activity). These differences could be due to processing effects on antioxidant components or inherent variation in the composition of the plant source.

Most refined white sugar worldwide is produced from the sugar cane plant (*Saccharum officinarum*, *S spontaneum*, *S barberi*, *S sinense*, and hybrids thereof), in tropical and subtropical locations, with the remainder coming from sugar beet (28). Sucrose is concentrated in the stalk of the sugar cane, which is harvested for sugar production. The cane is crushed to extract a sucrose-rich juice, then clarified, boiled to a thick syrup, and crystallized to yield raw cane sugar (28), also known as Sucanat, demerara, turbinado, muscavado, or juggeri. Refined sugar results after additional steps are performed to remove color and nonsugar components; and molasses is a byproduct of this process (28). Commercially available "brown sugar" is refined sugar with varying amounts of molasses added (~3.5% and 6.5%, respectively, for light and dark sugars). The relative assayed antioxidant content of molasses, light and dark brown sugar, and raw cane sugar (Table 1 and Figure) are consistent with the high concentration of antioxidants in the molasses syrup vs refined sugar. The higher antioxidant content might be a result of residual components from the sugar cane plant or from byproducts produced during the cooking of the cane juice. Duarte-Almeida and colleagues (29) found a substantial concentration of antioxidant phenolic acids (eg, hydroxycinnamic acids and sinapic acid) and flavonoids (eg, tricin and apigenin) totaling ~160 mg/L.

Maple syrup is produced from the clear sap of the tree, which is boiled and concentrated to yield what is sold as maple syrup. Maple syrup contains approximately 67% solids, mostly sugars, but also minerals and some vitamins, including notable amounts of calcium, potassium, manganese, magnesium, phosphorous, iron, and thiamin (30). Maple syrup also contains phenolic compounds, which also have antioxidant activity (31,32).

Honey is a sugar-rich liquid produced by bees from the nectar of flowers that is partially digested and then regurgitated into the hive and stored in the honeycomb, where evaporation of water concentrates the sugars (33). Honey can be sold raw or refined, with the latter being the case for most commercial retail products in the United States. Honeys assayed in the present study (Table 1) represent major available retail brands in the United States and probably clover as the nectar source because this is the predominant source for honey produced in the United States (34). Data do not reflect the composition of the full range of honeys from different nectar sources or various levels of refining. Phenolic compounds have been widely reported in honey and would be expected to vary with nectar source and level of refining; for example, Baltrušaitytė and colleagues (35) found a wide range of antioxidant capacity and phenolic components in honey from different sources, and Blasa and colleagues (36) found considerably greater antioxidant activity, phenolic, and flavonoid levels in raw *Millefiori* vs *Acacia* honey.

Somewhat surprising was the low antioxidant level in agave nectar, which is produced from the sap from hearts of the agave plant, a desert succulent. Agave nectar is the filtered juice expressed from the hearts (piñas) of the plant, which is then heated or enzymatically treated to hydrolyze the complex carbohydrates (mainly fructans) to sugars, then filtered and concentrated to a syrup (37). Although found to be low in antioxidants (similar to refined sugar, Table 1 and Figure), agave nectar is gaining popularity as a healthful alternative sweetener because of its low glycemic index (38,39). The taste and consistency of agave nectar are similar to corn syrup and, because it is unrefined, it might be expected to contain other beneficial non-antioxidant nutrients, trace elements, or phytochemicals.

Date sugar is made by grinding dried dates (the fruit of *Phoenix dactylifera sp.*), which contain 50% to 70% sugar, into a coarse powder (40). Because the product is the whole fruit it possesses the nutrient profile of dates, including considerable amounts of fiber, minerals, and vitamins [see (24), NDB numbers 09087 and 09421]. The antioxidant content of date sugars measured in the present study is consistent with the high FRAP analyzed in dates (0.565 to 0.718 mmol/100 g) (12). Use of date sugar might be limited to specific baking applications, however, because it contains 30% to 50% nonsugar com-

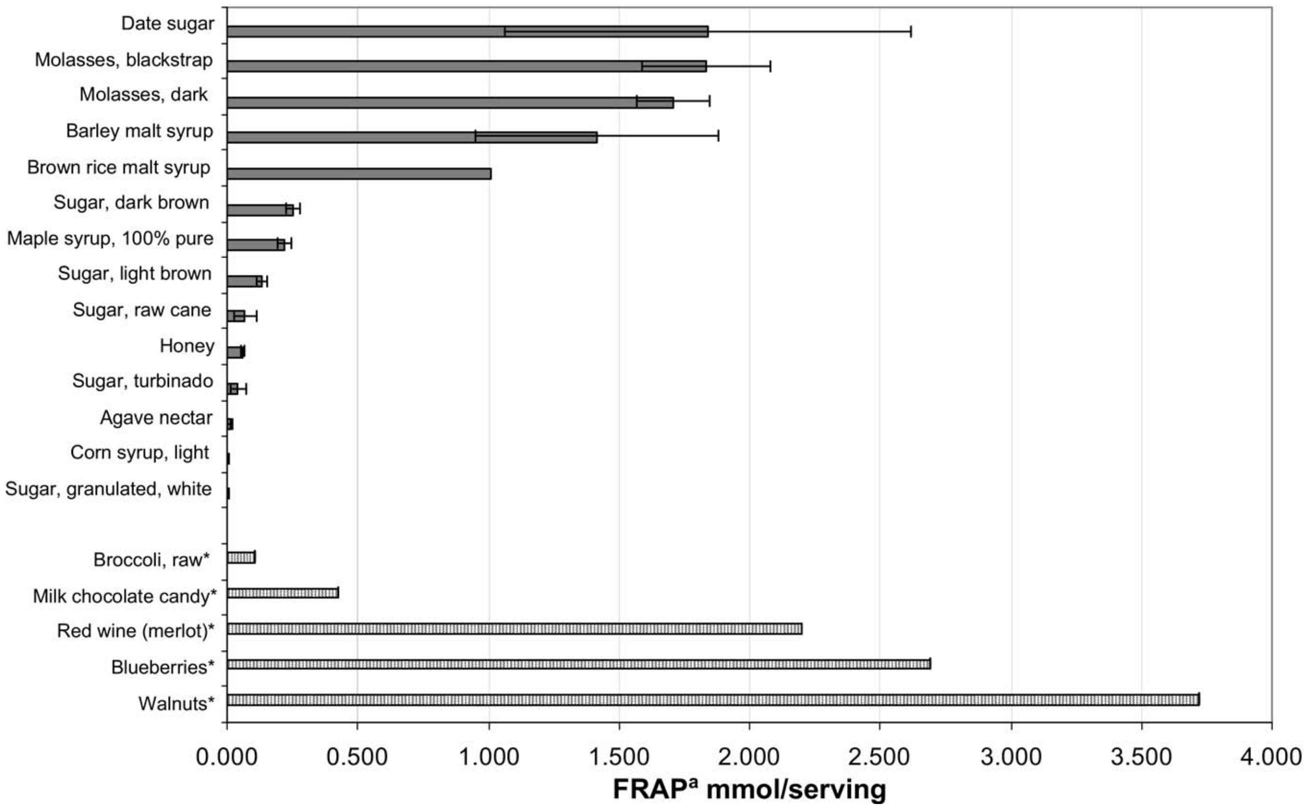

Figure. Estimated antioxidant contribution from sweetener used as a substitute for refined sugar in a standard cake recipe containing 1.5 cups (350 g) granulated sugar and yielding nine servings, compared to 1 serving of selected foods. *Data from Halvorsen and colleagues (12), serving sizes: walnuts, 1 oz. (28.35 g); blueberries, 1 cup (145 g); red wine (merlot), 3.5 oz (103 g); milk chocolate candy, 1 oz (28.35 g); broccoli, raw, 0.5 cup (44 g). Serving sizes for sweeteners: date sugar, dark brown sugar, light brown sugar, raw cane sugar, granulated white sugar, turbinado sugar: 1 oz (28.35 g); blackstrap molasses, dark molasses, barley malt syrup, brown rice malt syrup, maple syrup, agave nectar, corn syrup: 1 Tbsp (30 mL; 20 g); honey: 1 Tbsp (30 mL; 21 g). [a]FRAP=ferric-reducing ability of plasma.

ponents, which will not provide the physical properties needed in many applications, nor does it dissolve in liquids.

DISCUSSION

Potential Impact of Replacing Refined Sugar

Average intake of TAC, determined as FRAP, in a normal adult healthy population in Norway has been reported to be about 15 to 20 mmol (4), with the major contributors to dietary intake being coffee, fruits and berries, tea, wine, and cereals. In an Italian population (41), as measured by three different methods, coffee and tea beverages were the main contributors to TAC intake in women, followed by alcoholic beverages, fruits, and vegetables. In Italian men, the main contributors to TAC intake were alcoholic beverages, followed by coffee and tea, fruits, and vegetables. Similarly, coffee also has been reported to be a major dietary source of TAC in an American diet, followed by tea and other beverages (42).

Estimated average per capita consumption of added sugars in the United States is 130 g/day (18). Table 2 shows the calculated increase in antioxidant content that would result from direct substitution of alternative sweeteners (although not necessarily feasible in all products) for an amount equivalent to the sweetening power of 130 g refined sugar. On average, this amount was 2.6 mmol across all sweeteners (Table 2), ranging from 0.1 to 0.2 mmol (raw cane and turbinado sugars) to 10.7 mmol (blackstrap molasses). Relative to the mean total FRAP content of 17.3 mmol/day and 6.2 mmol/day (in diets including and excluding coffee, respectively), reported by Svilaas and colleagues (4), and of 2.8 mmol/day assayed in an "average American diet (43) (Phillips and colleagues, unpublished data), the contribution of 2.6 mmol/day represents a 15% to 92% increase, respectively. On an absolute basis, the potential increased antioxidant intake from these dietary modifications is similar to the contribution of tea (1.4 mmol/day) and fruit (1.8 mmol/day) in the diets studied by Svilaas and colleagues (4) and to the assayed FRAP content of blueberries (2.7 mmol/1 cup serving), red wine (2.2 mmol/serving) reported for individual foods (12).

Complete substitution of these sweeteners for refined sugar may not be realistic because of changes in product quality, but one possible application is simple replacement of refined sugar in recipes that are routinely prepared. For example, considering a cake prepared with 1.5

Table 2. Calculated increase in antioxidant content resulting from direct substitution of alternative sweeteners for refined white sugar

Product	Sweetening equivalent[ab] to 1 cup sugar (g)	FRAP mmol[c] equivalent to 130 g sugar	Increased mmol/day vs refined sugar
Refined sugar, white granulated	200	0.013	0.0
Raw cane sugar	200	0.186	0.2
Brown sugar, light	220	0.516	0.5
Brown sugar, dark	220	0.986	1.0
Turbinado sugar	200	0.110	0.1
Date sugar	220	4.681	4.7
Honey	339	0.352	0.3
Maple syrup, 100%	322	0.820	0.8
Molasses, dark	337	9.621	9.6
Molasses, blackstrap	337	10.721	10.7
Agave nectar[d]	336	0.085	0.1
Brown rice syrup	337	0.437	0.4
Barley malt syrup	337	2.207	2.2
Average of alternatives to refined white sugar			2.6

[a]Berthold-Bond and Atlas (52).
[b]From nutrition facts panel of product label, or US Department of Agriculture Nutrient Database for Standard Reference (24).
[c]FRAP=ferric-reducing ability of plasma; mean value based on results shown in Table 1.
[d]Mean of all types of agave nectar (Table 1).

cups (350 g) sugar to yield nine servings, the antioxidant content per serving would be increased by ~0.1, 0.25, 1.8, and 1.8 mmol if raw cane sugar, dark brown sugar, dark or blackstrap molasses, or date sugar, respectively, were used instead of refined sugar. These data suggest that the nutrient and antioxidant contribution of alternative sweeteners could be similar to that of whole vs refined flours (19) and foods high in antioxidants (eg, berries, chocolate, and nuts). For example, the FRAP (mmol/100 g) reported previously was 2.15 to 2.33 for blueberries, raspberries, and strawberries; 4.19 for unsweetened chocolate; and 9.67 to 13.12 for pecans and walnuts (12).

There are several examples that antioxidant-rich foods (eg, pomegranates, berries, and nuts) can dampen oxidative stress or reduce risk of developing oxidative stress-related diseases, such as cancer and cardiovascular diseases (44-46). It should be noted that, in general, various methods to estimate total antioxidant capacities/activities give same ranking of the items measured [see references (41,47,48)]. While the absolute values are most often not easily comparable between the methods and in various articles because the assays are performed differently (eg, different incubation time, concentrations), the main result is that the ranking of items is fairly consistent among assays. The dietary antioxidant activity based on measured TAC of foods needs to be correlated with physiological parameters related to oxidative stress in vivo, but the benefit of increasing antioxidant intake is generally recognized (49-51).

CONCLUSIONS

Data provided should be useful to researchers wishing to study the relationship between dietary antioxidants and physiological and/or health effects, as well as to registered dietitians making food-choice recommendations for increasing consumption of antioxidant-rich foods. Use of alternatives to refined sugar can add to the cumulative antioxidant content of the diet by replacing refined sugar. Development of recipes and consumer-friendly methods for replacing refined sugar in baking and cooking could increase antioxidant consumption similar to replacement of refined grains with whole grains.

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