United Sorghum Checkoff Fund Project - Final Report

Contract number: MD-1--17

August, 2018

Contracting Entity: United States Department of Agriculture – Agricultural Research Service

Project Title: High Value Markets for Sweet Sorghum Syrup

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Projected Start Dates:1 Sept 2017 to 1 Sept 2018

Update on Project Objectives/Experiments

The Overall Goal is to re-introduce sweet sorghum syrup as a commercial liquid food sweetener and nutritional food ingredient in the U.S.A. The specific goal is to develop comprehensive technical and nutrition data for sweet sorghum syrup food syrup (sugar profile, flavor, composition, etc.) and competitive attributes (non-GMO, gluten-free, etc.). This will be based upon samples provided by Delta BioRenewables LLC, Memphis, TN, Heckemeyer Mill, Sikeston, MO,and small-scale sweet sorghum producers and compared to the common sweeteners high fructose corn syrup (HFCS), honey, corn, agave, maple, sugarcane, rice, and grain sorghum syrups. Ultimately, Technical Data Sheets will be constructed for Sweet Sorghum Syrups, targeted for selected end-user market segments.

Collection of Commercial Syrups

Commercial samples of high fructose corn syrup (HFCS), corn syrup, agave syrup, honey, maple, sugarcane, rice, and grain sorghum syrups were purchased from local (New Orleans) supermarkets. At least three different commercial brands for each syrup type were purchased. If three brands could not be found locally, then they were purchased on-line. Ten various sweet sorghum syrups were obtained from Delta BioRenewables LLC, Memphis, TN, Heckemeyer Mill, Sikeston, MO, and also purchased from retailers all over the U.S.A. The collected syrups are listed in Table 1 with their stated main ingredients.

Experimental

*Oligosaccharides measured using ion chromatography with integrated pulsed amperometric detection (IC-IPAD).*An oligosaccharide fingerprint chromatogram (up to 12 DP) of each syrup was obtained by using a strong NaOH/NaOAc gradient over 40 min (Eggleston and Borges, 2015), using CarboPac PA1 analytical and guard columns (Dionex Corp., Sunnyvale, CA, USA) at 25 ˚C. All syrups were adjusted to 7.0 Brix prior to comparison. All determinations were performed in duplicate.

Table 1. List of Commercial Syrups Collected for the Study and Their Main Ingredients.

Syrup	Rep No.	Brand Name	Manufacturer	Major Ingredients
Corn	1	Light Corn Syrup	Winn Dixie	Light corn syrup, salt, vanilla
Corn	2	Light Corn Syrup	Karo	Corn syrup, salt, vanilla
Corn	3	Light Corn Syrup	Golden Barrel	Corn syrup, HFCS, vanilla, salt
Honey	1	Acadiana Honey	Bernard	Honey
Honey	2	Orange Blossom Honey	Winn Dixie	Honey
Honey	3	Clover Honey	SueBee	Honey
Agave	1	Organic Blue Agave	Wholesome Sweeteners	Organic blue agave nectar
Agave	2	Organic Blue Agave	Domino	Organic agave nectar
Agave	3	Organic Blue Agave	Trader Joe	Organic agave nectar
Maple	1	Amber Color Maple Syrup	The Fresh Market	Maple Syrup
Maple	2	Carys Maple Syrup	Carys	Maple Syrup
Maple	3	100% Pure Maple Syrup	Maple Grove Farms	Maple Syrup
Cane	1	100% Pure Cane Syrup	Steens	Pure sugarcane juice slow-simmered in open kettles
Cane	2	Monin Pure Cane Syrup	Monin	Refined cane sugar and water
Cane	3	Golden Syrup	Tate & Lyle	Cane sugar syrup
Sweet Sorghum	1	100% Pure Sorghum	Spring Valley Farms	Pure sweet sorghum syrup
Sweet Sorghum	2	Heritage Valley Sorghum Syrup	DBR*	Sweet sorghum syrup
Sweet Sorghum	3	Sweet Sorghum Syrup	Ozark Country	Condensed sweet sorghum juice
Sweet Sorghum	4	Sorghum	Maasdams	Sweet sorghum syrup
Sweet Sorghum	5	Sweet Sorghum Syrup	Muddy Pond	Sweet sorghum syrup
Sweet Sorghum	6	Sweet Sorghum Honey Drip	Heckemeyer	Sweet sorghum syrup
Sweet Sorghum	7	Sweet Sorghum Dale	Heckemeyer	Sweet sorghum syrup
Sweet Sorghum	8	Sweet Sorghum Topper	Heckemeyer	Sweet sorghum syrup
Sweet Sorghum	9	Sweet Sorghum Syrup	DBR	Sweet sorghum syrup
Sweet Sorghum	10	Sweet Sorghum Syrup	DBR	Sweet sorghum syrup
Rice	1	Brown Rice Syrup	Rawseed	
Rice	2	Korean Rice Syrup		Rice, water, amylase
Rice	3	Brown Rice Syrup	Lundberg	Eco-farmed brown rice, pure filtered water
Grain Sorghum	1	White Grain Sorghum Syrup	Briess	White sorghum grain, water
HFCS†	1	Original White Syrup	Aunt Jemima	HFCS, cellulose gum, water
HFCS	2	Lite Syrup	ShurFine	HFCS, cellulose gum, water

*DBR=Delta BioRenewables LLC, Memphis, TN
†HFCS=HighFructose Corn Syrup

*Brix (% dissolved refractometric solids), and pH.*Brix was measured using an Index Instruments (Kissimmee, FL) TCR 15-30 temperature controlled refractometer accurate to ± 0.01 Brix, and results expressed as an average of triplicates. The pH was measured on a Metrohm Brinkman 716 DMS Titrino (Riverview, FL, USA) with a Mettler Toledo (Columbus, OH, USA) xerolyte electrode.

Insoluble and Soluble Starch. Samples were analyzed for total, soluble, and insoluble starch using the microwave-assisted sonication/iodometric USDA Research method (Cole et al., 2016). Syrups were first adjusted to ~15 Brix before analyses and starch was assayed in triplicate; concentrations are quoted as average ppm on a Brix basis.

Moisture. Analyses followed method MWL FO 002 which references individual AOAC methods for specific materials including beef powders (AOAC 990.19), sugar (AOAC 925.45), flour (AOAC 925.09), pasta (AOAC 926.07), nuts (AOAC 925.40), dried fruits (AOAC 934.06) and others. Samples were weighed in a tin and placed in a vacuum oven, sealed, and the vacuum produced and temperature regulated. The vacuum level, temperature, and heating time are followed. After the specified time the samples are re-weighed and the loss in mass was reported as vacuum moisture. Results are expressed as averages of duplicate analysis.

Protein. AOAC 992.15 - Protein analysis was carried out using MWL FO 014 which is based on AOAC 992.15 and USDA/FSIS CLG-PRO04.03. Samples were weighed then combusted torelease nitrogen. The amount of nitrogen was determined and then multiplied by a factor to convert the nitrogen value to a protein value. The standard reporting level was ± 0.1% and results expressed as averages of duplicate analysis.

Fat. AOAC 922.06 - Analysis follows MWL FO 08 which is based on AOAC 922.06. The homogenized sample was treated with HCl and washed twice with petroleum ether and diethyl ether and the solution placed in a pre-weighed container. Fat was expressed as % on a wet weight basis and results are averages of duplicate analysis.

Ash. AOAC **-**Analysis follows MWL FO 022 which references individual AOAC methods for specific materials including meats (900.02, 920.155, 920.153), confectionaries (AOAC 900.02), spices (AOAC 941.12), pastas (AOAC 925.11), and others. The sample was weighed and ashed at 600 ˚C, cooled in a desiccator and re-weighed. The remaining residue was reported as ash. Ash was expressed as % on a wet weight basis and results are averages of duplicate analysis.

Minerals. Analysis of magnesium, iron, sodium, potassium, calcium, and phosphorus followed USP 233 - Analysis follows MWL ME 042 which is based on USP 233 and EPA 6010b, Inductively Coupled Plasma (ICP). A light emission technique where prepared samples are injected into a high energy plasma that forces the elements in the injected sample to emit light wavelengths that are specific to each metal present. The intensities of which are proportional to the level of minerals and metals present. The light was then detected and correlated to the levels of minerals and metals in the original sample.

Carbohydrate. Total carbohydrate (soluble and insoluble) in the syrups were calculated by difference by using the following equation: Carbohydrates = 100 - (% Moisture) - (% Fat) - (% Protein) - (% Total Ash).

Calories. The caloric value (Cal or kcal) for each syrup were calculated by using the following equation: Fat x 9.0 + Protein x 4.0 + Carbohydrates x 4.0 = Calories. This was based on the caloric value for fat, protein, and carbohydrates which are 9.0, 4.0, and 4.0 kcal/g, respectively.

Calculation of Nutritional Food Label Data. The nutritional labelling data for one serving size of syrup was calculated. The serving size on the labels for each syrup in this study varied widely. For example, all the maple and HFCS syrups had a serving size of ¼ cup (4 U.S. tablespoons tbsp equivalent to 60 mL which is equivalent to a density of 1.00); honey, agave, and cane syrups 1 tbsp (21 g; density ≡ 1.40, corn 2 tbsp (30 mL≡ 1.00); rice syrups 2 tbsp (30 mL or 40 g ≡ 1.33); maple syrups varied from 4 tbsp to ¼ cup (density ≡ 1.00). After discussions with dieticians, it was decided to calculate the nutritional data for all the syrups in this study based on 1/8 cup (2 tbsp; 30 mL) using the average density values for each syrup type.

Total Phenolic Content (TPC). The TPC of each syrup was determined using a Folin–Ciocalteu method with minor modifications, using gallic acid as the standard (Singleton et al. 1999). The syrup (0.1 g) was first diluted 10-fold with deionized water (9 mL). Into a glass test-tube, diluted sample (125 µL) and 625 µL of Folin–Ciocalteu reagent (0.2N) were first pipetted, vortex mixed, and then allowed to stand at room temperature (~25 ˚C) for 4 min. Then, 500 µL of 7.5% Na_2CO_3 was added to the mix, vortexed, the tube covered, and then incubated in a water bath set at 40 ˚C for 30 min. The solution was then added to a disposable cuvette and the absorption read at 760 nm on a UV-vis spectrophotometer (UV mini-1240 model, Shimadzu, Houston, TX). A standard curve was generated using seven levels of gallic acid (0, 25, 50, 100, 150, 200, and 250 µg/mL). All determinations were carried out in triplicate, and the results are expressed as mg of gallic acid equivalent (GAE) per gram of extract.

Color and Indicator Values. Color was calculated according to the official ICUMSA method GS2/3-9 (1994) for sugarcane products, with slight modifications. For sugarcane products color is measured as absorbance at 420 nm but the color of the syrups in this study were also measured at 280, 320, 420, and 510 nm since preliminary results indicated higher activity of phenolic compounds at these lower wavelengths. Syrups (~5 mL) were diluted in triethanolamine/ hydrochloric acid buffer (5 mL; pH 7.0) and filtered through a 0.45 µm PVDF filter. Color was also measured at pH 4.0 and 9.0 by using buffers that were first pH adjusted with HCl and NaOH solutions, respectively. The Indicator Value (I.V.) was measured as the ratio of color at pH 9.0/color at pH 4.0. Results are expressed as an average of triplicates.

Antioxidant activity determinations. The free radical scavenging activity of the various syrups was determined according to the 2,2-diphenyl-1-picryl hydrazyl ($DPPH^{\cdot}$)method of Brand-Williams (1995) with some modifications by Boue et al. (2013). DPHH radicals have an absorption maximum at 517 nm, which disappears with reduction by an antioxidant compound. Antioxidant active compounds were first extracted from each syrup (1 g) by dissolving it in 9 mL of 70:30 methanol-deionized water mixture. The supernatant extract was used in the DPPH assay. The DPPH radical solution at a final concentration of 0.1 mM in methanol was prepared daily, and 190 µL was added to each well of a 96-well plate followed by a 10 µL of extracted sample, or methanol for the blank. The mixture was incubated at 30 ˚C for 30 min, and the absorbance at 517 nm was measured with a Tecan Sunrise Microplate Reader (Morrisville, NC). Lower absorbance indicates higher free radical scavenging activities. The inhibition percentage of the radical scavenging activity (RSA) was calculated using the following equation:

$$\text{Inhibtion (RSA)}\% = 100 - 100\left(\frac{\text{As}}{\text{Ao}}\right)$$

Where Ao is the absorbance of the blank and As is the absorbance of the extracted sample at 517 nm. All determinations were performed in triplicate.

ORAC (Oxygen Radical Absorbance Capacity) of each syrup was also measured using the Zen-Bio (Research Triangle Park, NC)ORAC kit. The assay measures the loss of fluorescein fluorescence over time due to peroxyl-radical formation by the breakdown of AAPH (2,2-axobis-2-methyl-propanimidamide dihydrochloride). Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), a water soluble vitamin E analog, served as a positive control inhibiting fluorescein decay in a dose dependent manner. All determinations were performed in triplicate using a BioTek Synergy H1 microplate reader.

Flavor Lexicon. The flavor lexicon was generated by nine trained flavor descriptive evaluation panelists. This lexicon was established by evaluating multiple sweet sorghum syrups, as well as corn syrup, honey, agave syrup, maple syrup, sugarcane syrup and brown rice syrup. Panelists evaluated the intensity of each attribute on each syrup sample by smelling and tasting the syrup. Panelists cleansed their mouths with ultra-filtrated water and un-salted saltines. They evaluated only five samples per session to prevent over saturation of the palate.

Statistics. Results were statistically analyzed using one-way ANOVA, with means ranked using Tukey's HSD at the 5% probability level. The analyses were conducted with JMP Pro 13 software (SAS Institute, Inc., Cary, NC). Standard deviations and coefficients of variation (CV) were calculated using Microsoft^{TM} Excel (ver. 2013).

RESULTS

Screening of Syrups for Adulteration

All the obtained syrups were first screened for adulteration with less expensive syrups, typically HFCS or corn syrups. The ion chromatography fingerprint oligosaccharide profile technique of Eggleston et al. (2016) was used to determine authentication. One sugarcane syrup and one sweet sorghum syrup were found to be adulterated with HFCS and, therefore, removed from the study and replaced with authentic syrups. Example oligosaccharide chromatograms of the various syrups are shown in Figs. 1 and 2. Fig. 1 illustrates that the three brands of each corn, honey, and especially agave syrups had very similar oligosaccharide profiles. The honeys contained more oligosaccharide peaks as expected, as they are source of specific oligosaccharides that are not found elsewhere (Eggleston, 2008). Fig. 2 of select (six) sweet sorghum syrup brands show the numerous similarities among the syrups.

Syrup Physical and Chemical Compositional Analyses

The total dissolved (soluble) solids, pH, and turbidity of the syrups were determined and are listed in Table 2. As expected there was a strong negative relationship (R^2=0.881; y=-0.8319 + 92.779) between the Brix (y axis) and moisture (x axis). No other significant relationships were found among the physical parameters listed in Table 2.

The HFCS syrups had the lowest ($P<0.05$) Brix values (38.9 - 41.2%), and the Brix concentrations of the other syrups varied ($P<0.05$) from ~63 to 82%. Except for honey, which is harvested as a concentrated solution, the Brix value of syrup is a reflection of how much the syrup manufacturers wanted to concentrate the syrup.

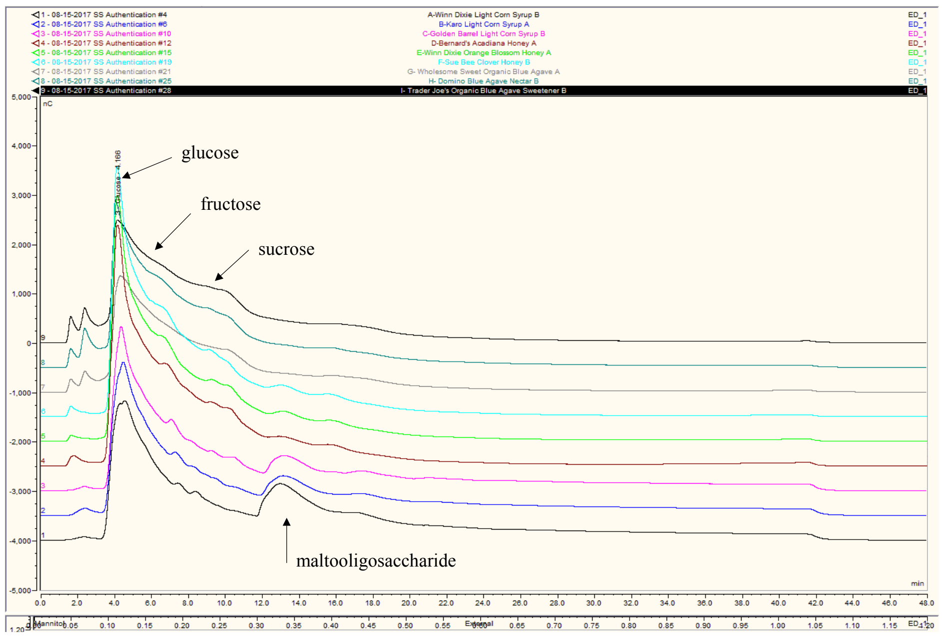


Fig. 1. Ion chromatography oligosaccharide fingerprint profiles of corn syrup, honey, and agave brand syrups. All syrups were 7.0 Brix.

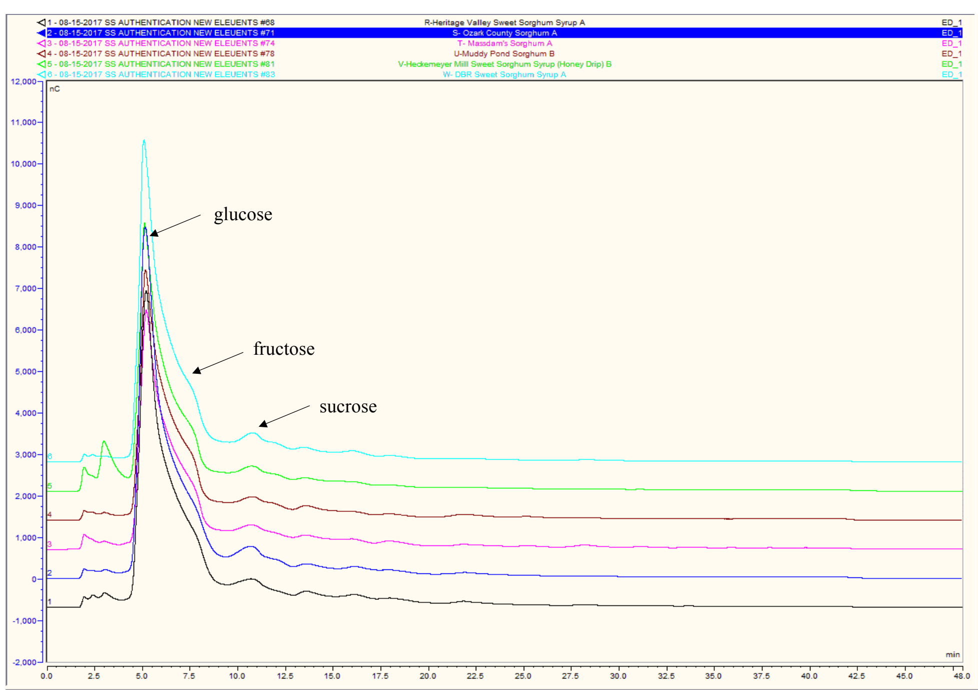


Fig. 2. Ion chromatography oligosaccharide fingerprint profiles of corn syrup, honey, and agave brand syrups. All syrups were 7.0 Brix.

Table 2. Differences in theMean Brix, Moisture, pH Values Among the Syrups.

Syrup	Rep No.	Brix %	Moisture %	pH
Corn	1	77.18GH*	19.8HIJ	3.34R
Corn	2	76.18HI	20.7H	2.51T
Corn	3	79.89BCD	17.0M	2.64T
Honey	1	80.09ABCD	13.0PQ	3.75Q
Honey	2	81.10A	11.7Q	3.07S
Honey	3	80.14ABCD	12.6PQ	3.15RS
Agave	1	75.35IJ	19.6HIJK	3.97NOP
Agave	2	75.95IJ	18.8IKL	5.94C
Agave	3	75.42IJ	19.0IJKL	4.79FGH
Maple	1	65.08LM	33.1D	6.44B
Maple	2	66.00L	34.1D	6.54B
Maple	3	65.72LM	33.3D	7.09A
Cane	1	76.23GH	17.8LM	4.78FGH
Cane	2	81.39M	31.1E	4.91DEF
Cane	3	79.22BCDE	13.5OP	4.99DE
Sweet Sorghum	1	80.24BCD	14.4NO	4.29LM
Sweet Sorghum	2	77.49FG	20.2HI	3.88PQ
Sweet Sorghum	3	77.27FGH	13.6OP	4.15MN
Sweet Sorghum	4	78.38EF	18.4KL	4.69GHI
Sweet Sorghum	5	74.80J	16.6M	4.56IJK
Sweet Sorghum	6	67.20K	29.2F	5.06D
Sweet Sorghum	7	76.29HI	27.8G	4.69GHI
Sweet Sorghum	8	63.33N	36.4C	5.03D
Sweet Sorghum	9	75.63IJ	20.6H	3.93PQ
Sweet Sorghum	10	80.39AB	16.7M	4.83EFG
Rice	1	77.16ABCD	17.1M	4.83EFG
Rice	2	80.39CDE	17.7M	4.47JKL
Rice	3	80.27ABC	15.0N	4.63HIJ
Grain Sorghum	1	79.06DE	17.8M	5.02DE
HFCS	1	38.93P	59.2A	4.37KL
HFCS	2	41.16O	57.0B	4.08NO
Overall Range:		**38.93 – 81.39**	**11.7 – 59.2**	**2.51 – 7.09**
Sweet Sorghum Range only:		**63.33 – 80.39**	**13.6 – 36.4**	**3.88 – 5.06**

*Means followed by a different upper case letter are significantly different at the 5% probability level

The brand T sweet sorghum syrups (reps 6 and 8) had lower Brix values than the other syrups because they were manufactured for potable ethanol production rather than as food syrups. The higher the final Brix then generally the lower the water activity of the syrup, which equates to better and longer storage capacity of syrups. On the other hand, the concentration of juices into syrups is a very expensive and energy-intensive step during processing. For example, in the maple syrup industry the syrups are only concentrated to ~65 Brix because of the high cost of concentrating an initial tree sap containing only ~2.0 Brix. Too high a concentration can also cause crystallization and precipitation of sucrose. As expected there was a strong negative relationship ($R=-0.975$) between the Brix or moisture contents of all the syrups. No other significant relationships were found among the physical parameters listed in Table 2.

The pH values of all the syrups varied ($P<0.05$) widely from 2.51 to 7.09 (Table 2). The lower pH syrups may impact their sour flavor characteristics. The pH of the three maple syrup brands were the highest (mean 6.69). The pH of the honey, agave, rice, HFCS, and sweet sorghum syrups varied ($P<0.05$) considerably with brand which most likely reflected differences in the raw materials and in processing parameters. The pH of the sweet sorghum syrups varied from 3.88 to 5.06. Most fresh sweet sorghum juices vary between 4.90 and 5.70, thus the lower pH values in the syrups mostly reflect the extent of the acid degradation of sucrose, glucose, or fructose during processing (Eggleston et al. 2016). The pH of the two HFCS syrups were 4.37 and 4.08, and these low values can at least partially be explained by the addition of sorbic or citric acids, and sodium benzoate (the sodium salt of benzoic acid) preservatives (Table 1).

Starch

The total, insoluble, and soluble starch contents of the various commercial syrups are shown in Fig. 3. Honey, agave, and maple syrups contained no starch. Cane syrups contained low amounts (up to 217 ppm/Brix) of total starch, but the cane sugar (rep 2; Table 1) manufactured from refined cane sugar contained no starch because the refinery process removed it. Corn and particularly HFCS syrups contained starch, which reflects the residual starch left after enzyme action on the corn starch to hydrolyze it to glucose. (Note: Compared to corn starch manufacture, HFCS undergoes an extra step when the glucose is transformed into fructose using an isomerase enzyme). Rice starch contained the highest amounts of starch (up to 5912.6 ppm/Brix), but the ratio of insoluble to soluble depended strongly on the brand (Fig. 3). This most likely reflects variations in processing of rice syrups.

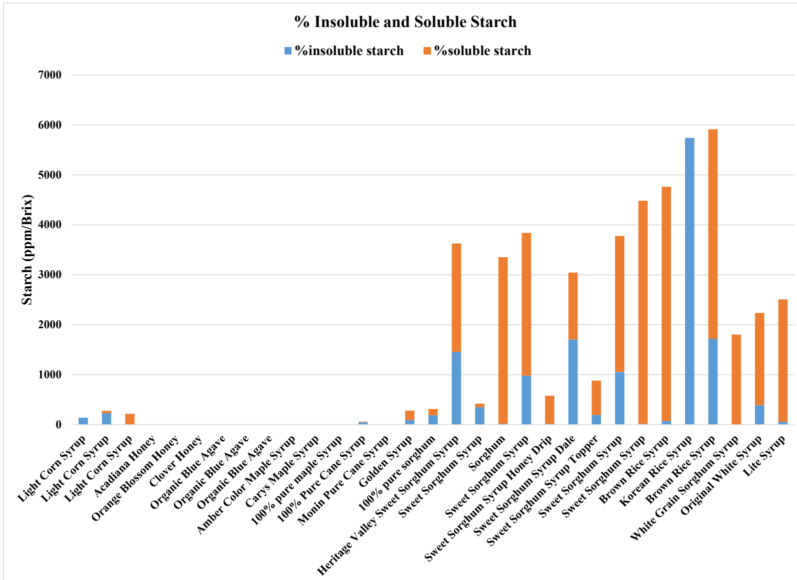


Fig. 3. The insoluble and soluble starch content of the various commercial syrups. The height of the column indicates total starch (insoluble + soluble) content.

Total starch in the sweet sorghum syrups ranged from 315 to 4482 ppm/Brix, and the ratios of insoluble to soluble starch varied considerably as well. The relative starch content in sweet sorghum is known to be high and can reach up to 18000 ppm/Brix (Eggleston et al. 2017), and is also highly dependent on cultivar. The best method to remove starch from sweet sorghum is via physical removal via sedimentation and juice clarification (Eggleston et al. 2016) because the action of high temperature stable amylase is limited on such starch due in part to its low susceptibility (Eggleston et al. 2017). Nevertheless, sweet sorghum starch removal is critical during processing of syrup as it can precipitate onto heating coils and burn, creating unwanted flavors and burnt scaling. Overall, starch in syrups will contribute to Calories and possible viscosity, but will not affect flavor.

Food Proximate Analyses of the Syrups: Macronutrient Contents

The protein, fat, carbohydrate, total ash, and Calorie contents of all the syrups are listed in Table 3. In the U.S.A., protein has evolved from being simply a macronutrient ingredient to being considered a benefit in itself, like fiber and calcium (Mellentin, 2017).In particular, high protein levels are currently a big consumer trend for functional beverages such as meal replacement, sports, and energy drinks. Moreover, high protein claims consisted of 40% of the new launches in 2015 which are "edging-out" high fiber claims (Pelofske, 2017). Additionally, protein source claims from natural plant sources are especially surging, while gluten and dairy proteins are on the decline (Pelofske, 2017; Mellentin, 2017). Decker and Prince (2018) also recently reported that the shift to demand for food products with plant protein is coming from young people and there is currently concern whether there are sufficient sources of plant protein to meet demand. Such trends are favorable for sweet sorghum syrups since, as shown in Table 3 they tended ($P<0.05$) to contain more protein than the other syrups.

Table 3. Differences in the Mean Macronutrient and Calorie Contents of the Sweet Sorghum Syrups Compared to Other Commercial Syrups.

Syrup	Rep No.	Protein %	Fat %	Carbohyd %[a]	Total Ash %	Calories Cal
Corn	1	0.6HIJKLM[b]	<0.1G	79.5EF	0.1KL	320.9JK
Corn	2	0.5 HIJKLM	<0.1G	78.8FGHI	<0.1KL	317.4KL
Corn	3	0.4JKLM	0.2EFG	82.4BC	<0.1L	332.8GH
Honey	1	0.7HIJK	0.4EFG	85.7A	0.2JKL	355.2A
Honey	2	0.8HIJK	0.5EFG	87.0A	<0.1KL	349.2AB
Honey	3	0.6HIJKLM	0.2EFG	86.6A	<0.1KL	350.4AB
Agave	1	0.4JKLM	0.9CDEFG	79.1FGHI	<0.1L	325.9IJ
Agave	2	0.1M	2.1B	78.7FGHI	0.3HIJKL	334.3EFGH
Agave	3	0.3KLM	3.3A	77.4GHIJ	<0.1KL	340.4CDE
Maple	1	0.2LM	0.7CDEFG	65.8M	0.3IJKL	270.0OP
Maple	2	0.4JKLM	0.4EFG	64.4M	0.6HIJK	263.4P
Maple	3	0.4JKLM	0.9CDEFG	64.8M	0.7HIJ	268.5P
Cane	1	0.4JKLM	1.2BCDEF	80.1DEF	0.4HIJKL	331.1FGH
Cane	2	0.4JKLM	0.5EFG	67.9L	0.1JKL	277.6N
Cane	3	0.6HIJKLM	0.9CDEFG	82.7B	2.3F	341.5CD
Sweet Sorghum	1	4.0A	1.7BCD	77.0IJK	3.0DE	338.9DEFG
Sweet Sorghum	2	1.0FGH	1.0CDEFG	75.2K	2.6DEF	313.4LM
Sweet Sorghum	3	1.9CD	0.6DEFG	81.8BCD	2.1F	339.8DEF
Sweet Sorghum	4	1.0GH	0.7CDEFG	76.8IJK	3.2CD	317.1KL
Sweet Sorghum	5	2.2BC	0.5DEFG	79.2FGH	1.4G	329.2HI
Sweet Sorghum	6	1.6DE	0.6DEFG	66.3LM	2.3F	276.7NO
Sweet Sorghum	7	1.6DE	1.3BCDE	65.7M	3.6BC	280.9N
Sweet Sorghum	8	2.4B	1.1BCDEFG	55.7N	4.4A	242.3Q
Sweet Sorghum	9	0.9GHI	<0.1G	75.8JK	2.6EF	307.6M
Sweet Sorghum	10	1.5DEF	0.7CDEFG	77.2HIJK	4.0AB	320.8JK
Rice	1	0.7HIJKKL	0.4EFG	81.7BCDE	0.1JKL	333.2FGH
Rice	2	0.9GHIJ	0.4EFG	80.6CDEF	0.3HIJKL	330.0HI
Rice	3	1.4EFG	1.8BC	81.3CDEF	0.5HIJKL	346.9AB
White Grain Sorghum	1	1.4DEFG	0.1FG	79.4EFG	1.3G	324.3IJ
HFCS	1	0.3KLM	0.4EFG	39.3P	0.9GH	161.7S
HFCS	2	0.3KLM	0.1FG	41.7O	0.8GHJ	169.3R
Overall Mean:		**0.96**	**0.84**	**74.1**	**1.52**	**258.8**
Sweet Sorghum Mean:		**1.81**	**0.91**	**73.1**	**2.92**	**306.7**
Overall Min. to Max:		**0.1 – 4.0**	**<0.1 - 3.3**	**55.7 – 81.8**	**<0.1 – 2.3**	**161.7 – 355.2**
Sweet Sorghum Min. to Max.:		**0.9 – 4.0**	**<0.1 – 1.7**	**39.3 – 87.0**	**1.4 – 4.4**	**276.7 – 346.9**

[a]This includes soluble and insoluble carbohydrate

[b]Means followed by a different upper case letter are significantly different at the 5% probability level for a column only.

The protein content of sweet sorghum syrups ranged from 0.9 to 4.0%, and the mean value (1.80%) was nearly two-fold higher than for the other syrups (0.96%). Thus, sweet sorghum syrups are a source of non-dairy and non-gluten plant protein. The white grain sorghum syrup contained 1.4% protein as did one of the rice syrup brands (rep 3), but all the others contained < 1.0%. It must be noted that two brands (reps 1 and 2) of rice syrup had amylase enzymes added as ingredients (Table 1) which will have added to their natural protein contents. The third (rep 3) brand of rice syrup, however, still contained the highest amount of protein (Table 3). This also most likely explains why the rice syrups had higher ($P<0.05$) protein levels than corn and HFCS starch-based syrups (Table 3).

Except for agave, maple, and cane syrups, the fat content of the syrups tended to be lower than the protein content (Table 3). The fat content of sweet sorghum syrups ranged from <0.1 to 1.7%, whereas the range for all the syrups was <0.1 to 3.3%. Sweet sorghum stalks are known to have a waxy surface which will have contributed to the fat composition of the sweet sorghum syrups. Likewise, sugarcane stalks are covered in wax. The agave syrups contained the highest amount of fat (mean 2.1%) and, except for rep 1 agave syrup, this was significantly different at the 5% probability level (Table 3). Blue agave leaves are known to be covered with a thick layer of blue-colored wax that protects them from evaporation and insects.

The per cent carbohydrate (both soluble and insoluble) contents of the syrups are also listed in Table 3. These values will have included sucrose, glucose, and fructose soluble sugars as well as insoluble and soluble starch. The carbohydrate values were strongly dependent on the Brix ($R=0.987$) contents and inversely dependent ($R=-0.982$) on the moisture contents.

The total per cent (incinerated) ash content is a reflection of the total mineral content in each of the syrups (Table 3). The human body requires a steady and adequate supply of essential and trace minerals. Total ash content ranged from 1.4 to 4.4% in the sweet sorghum syrups whereas it only ranged from <0.1 to 2.3% in the other syrups. Furthermore, the mean ash content for the ten sweet sorghum syrups (2.92%) was nearly twice as high ($P<0.05$) as the mean value for the other syrups (1.52%). Nimbkar et al. (2006) reported that sweet sorghum syrup manufactured from Madhura cultivar in India had 6.25-fold higher ash than honey, although only two samples were compared. This strongly indicates that sweet sorghum syrups are a rich source of dietary minerals. For all the syrups, potassium, calcium, and magnesium were the greatest contributors to the total ash with R correlations of 0.921, 0.822, and 0.725, respectively. The other minerals were found not to be significantly correlated with total ash, so are more limited contributors. It is possible that the much higher dietary mineral content in sweet sorghum is related to its high rate of growth compared to many other sugar crops, but more studies are needed to investigate this.

Sucrose, Glucose, and Fructose Contents

As shown in Table 4, the glucose, fructose, and sucrose concentrations varied widely and significantly among the syrups. As expected, the starch based syrups corn, rice and HFCS did not contain any sucrose although the white grain sorghum did. Although the corn and rice syrups are low in these soluble sugars, they will be contain maltose and related oligosaccharides. The agave syrups contained very high amounts of fructose and much more than HFCS, therefore, they are "high fructose" syrups. Sucrose, glucose, and fructose in the sweet sorghum brands varied significantly ($P<0.05$) with brand. This is most likely due to differences in sweet sorghum cultivars and processing.

Table 4. The glucose, fructose, and sucrose contents (percentage on syrup basis) for all the syrups.

Commercial Syrup	Rep No.	Glucose %	Fructose %	Sucrose %
Corn	1	2.02 J*	0 O	0 K
Corn	2	2.79 I	0 O	0 K
Corn	3	3.52 H	0 O	0 K
Honey	1	4.07 G	3.49 JK	0 K
Honey	2	4.18 FG	3.83 H	0 K
Honey	3	4.47 M	4.06 C	2.90 J
Agave	1	0.02 LM	10.70 A	0 K
Agave	2	1.56 K	7.67 C	0 K
Agave	3	0.02 M0	9.40 B	0 K
Maple	1	0 M	0 O	15.20 C
Maple	2	0 M	0.02 O	15.01 C
Maple	3	0.04 M	0.05 O	15.22 C
Cane	1	3.40 H	3.79 H	8.20 F
Cane	2	2.56 I	2.62 M	11.52 D
Cane	**3**	3.49 H	3.44 K	6.67 GH
Sweet Sorghum	**1**	5.11 C	4.54 F	8.90 EF
Sweet Sorghum	**2**	3.53 H	3.11 L	2.05 J
Sweet Sorghum	**3**	5.08 C	4.90 E	2.03 J
Sweet Sorghum	**4**	3.38 H	2.37 M	7.73 FG
Sweet Sorghum	**5**	4.32 EFG	3.88 H	21.59 A
Sweet Sorghum	**6**	4.18 FG	2.55 L	17.76 B
Sweet Sorghum	**7**	4.94 CD	3.61 IJ	4.46 I
Sweet Sorghum	**8**	4.33 EFG	2.61 M	3.21 IJ
Sweet Sorghum	**9**	4.15 FG	3.64 I	5.88 H
Sweet Sorghum	**10**	4.15 FG	3.41 K	9.58 E
Rice	**1**	1.45 K	0 O	0 K
Rice	**2**	1.76 JK	0 O	0 K
Rice	**3**	4.69 DE	0 O	0 K
White Grain Sorghum	**1**	0.52 L	0 O	3.12 IJ
HFCS	**1**	6.73 A	6.54 D	0 K
HFCS	**2**	5.70 B	4.84 E	0 K

*Means followed by a different upper case letter are significantly different at the 5% probability level for a column only.

Syrup Total Phenolic Content, Antioxidant Capacity, and Color

Plant phenolic compounds, including flavonoids, have been recognized as important phytonutrients due to their physiological (Cody et al. 1988) and pharmacological (Cermak and Wolffram, 2006) roles, as well as numerous health benefits (Balasundram et al. 2005; Hooper and Cassidy, 2006). Such dietary benefits of phenols are linked to their strong antioxidant and radical scavenging activity. Free radicals in the body are associated with aging, cancer, neurodegenerative diseases and cardiovascular disease (Pelofske, 2017). As a consequence, nutraceutical ingredients such as antioxidants allow for health and wellness claims for a particular foodstuff (Pelofske, 2017). Phenolic compounds are frequently found in fruits, vegetables, and cereals (Balasundram et al. 2005) and are also available in concentrated form in botanical extracts, e.g., cranberry extract. However, as shown in Fig. 4 total phenolics also occur in high amounts in sweet sorghum syrups and all brands were significantly (P<0.05) higher than the other syrups.

The ten sweet sorghum syrups (mean ± std. dev. 6471 ± 1823 mg/L) had dramatically (P<0.05) higher TPC than the other commercial syrups (596 ± 497 mg/L). Furthermore, the variation in the TPC of the ten brands of sweet sorghum syrups was only 28.2% CV compared to a CV of 83.3% for the other syrups. Flavonols (procyanidins), anthocyanins, tannins (water-soluble phenolic compounds with a molecular weight of >500 Da which exist in either hydrolysable or condensed forms), and phenolic acids are also known to occur in grain sorghum (*Sorghum bicolor*), and phenols have been reported to be largely responsible for the antioxidant activity of grain sorghum (Awika et al. 2003). The white grain sorghum syrup in this study also contained moderately high amounts of TPC (1620 mg/L) (Fig. 4). To put these results into perspective, the average TPC content of sweet sorghum syrup (6471 mg/L) was markedly higher than for pomegranate (2882 mg/L) and cranberry (1798 mg/L) juices using the same analytical method (Eggleston, 2018). The latter two juices have lower Brix values than syrups and are marketed for their high antioxidant capacity.

Compared to the sweet sorghum syrups the other commercial syrups contained only moderate to low TPC amounts with HFCS and corn syrups containing the lowest amounts (Fig. 4). Overall, the mean TPC amounts in all the syrups followed the order:

Sweet sorghum>>>grain sorghum>rice>sugarcane>honey>agave=maple>>HFCS>>Corn

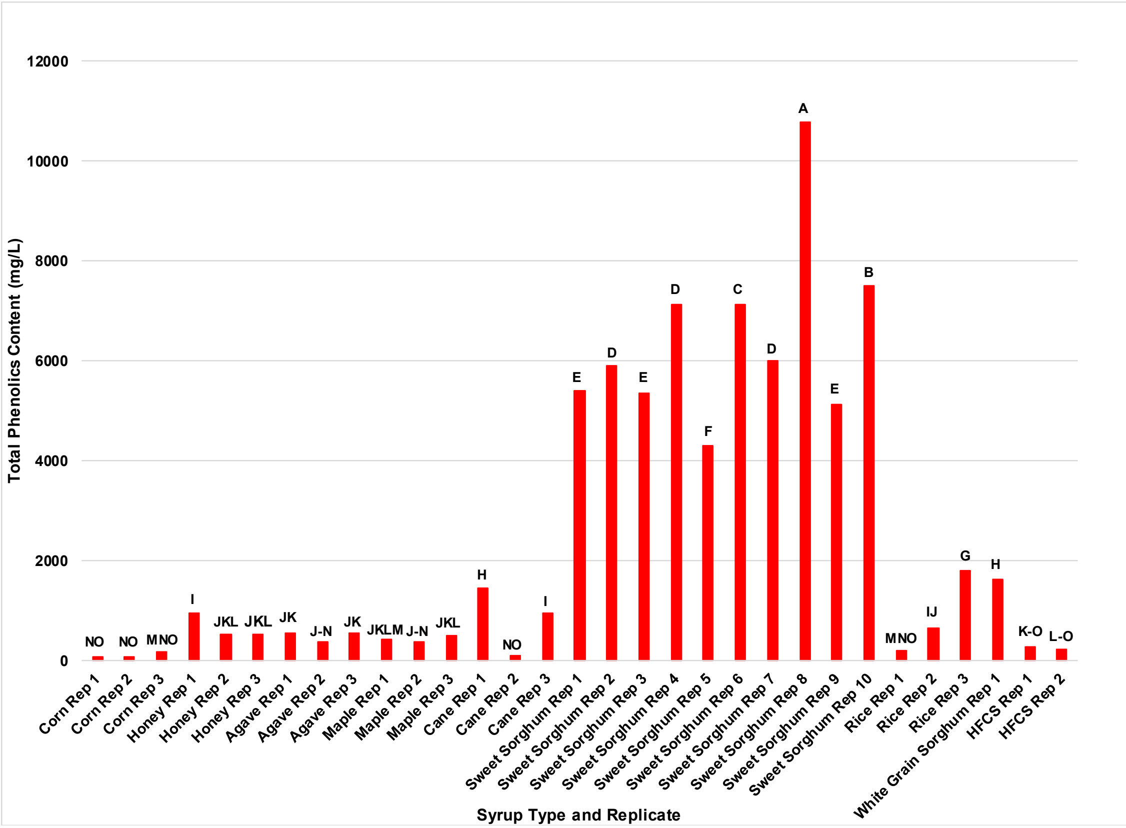


Fig. 4. The average total phenolic content (TPC) of commercial syrups. Results are expressed in mg/L which are equivalent to milligrams of gallic acid equivalents/L. Means followed by a different upper case letter are significantly different at the 5% probability level.

The percent radical scavenging activity (RSA) results based on the scavenging capacity of the DPPH radical are illustrated in Fig. 5. There were significant ($P<0.05$) differences in the DPPH-RSA values of the syrups with only maple syrups having values that were *not* significantly lower than sweet sorghum syrups. The DPPH scavenging activity of phenolic compounds has been shown to be positively correlated with the number of hydroxyl groups it possesses (Sroka and Cisowski, 2003). The RSA was moderately positively correlated ($R^2=0.669$; $y=1E\text{-}07x^2+0.0027x+2.824$) with TPC, but when the maple sugars (outliers) were removed the correlation increases markedly to $R^2=0.853$. Maple syrups have been reported to contain unique phenolic compounds such as quebecol (Arnaud, 2014), which may explain why they skewed the results. Gorinstein et al. (2004) reported that phenolic compounds in orange juices were strongly correlated with the antioxidant capacity determined by DPPH. Results in Fig. 5 also showed that HFCS, corn, grain sorghum, and rice syrups had no or negligible DPPH-RSA values and are, therefore, *not* good sources of antioxidants.

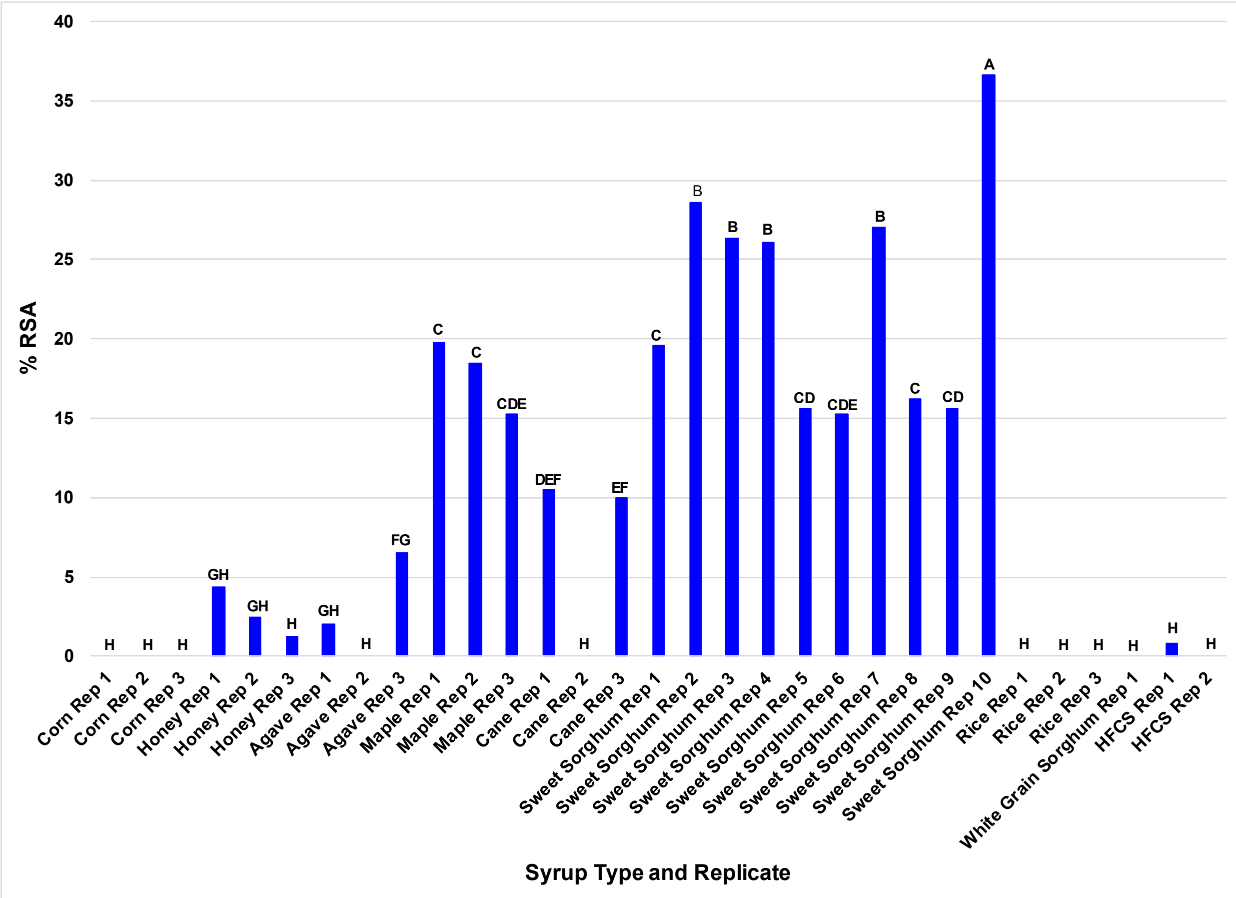


Fig. 5. The average DPPH radical scavenging activities (RSA) of commercial syrups. Means followed by a different upper case letter are significantly different at the 5% probability level.

The low RSA value for white grain sorghum in this study (Fig. 5) was not surprising as Awika et al. (2003) reported low values for white grain sorghum compared to red, brown, black, and hi-tannin grains. Since the TPC of the white grain sorghum in this study was 1620 mg/L (Fig. 4), the low RSA result suggested that antioxidant inhibitory or interfering compounds were present. Among the ten sweet sorghum brands the RSA values (Fig. 5) tended to vary more than their TPC values (Fig. 4), which similarly suggests that inihibitor/interfering compounds or possibly other components present in the sweet sorghum syrups that contributed to their DPPH-RSA. For example, sucrose has been reported to display antioxidant behavior (Tsang and Clarke, 1988).

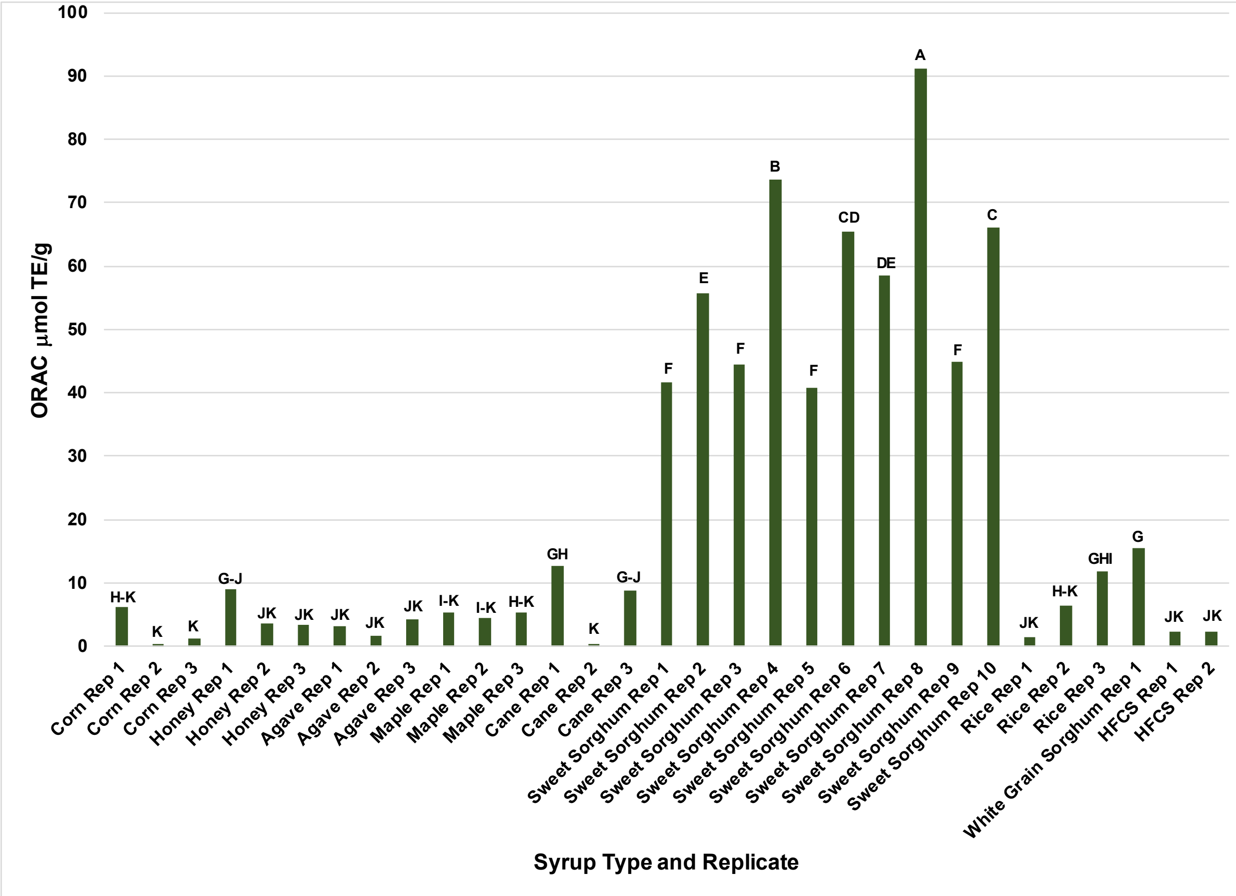


Fig. 6. The average ORAC values of the commercial syrups. Means followed by a different upper case letter are significantly different at the 5% probability level.

Since the DPPH radical is foreign to biological systems, the antioxidant activity of the syrups was further probed with ORAC (Oxygen Radical Absorbance Capacity) developed by Cao et al. (1993), and results are illustrated in Fig. 6. Similar for the DPPH-RSA results (Fig. 5) but to an even greater extent, the ORAC values of the sweet sorghum were dramatically higher ($P<0.05$) than for the other syrups and significant ($P<0.05$) differences occurred among the sweet sorghum brands. When all the syrups were considered, the ORAC values correlated ($R^2=0.987$; Fig. 7) very strongly with the TPC which was more strong than the relationship between TPC and the DPPH-RSA values ($R^2=0.669$). These results confirms that the total phenols are largely responsible for the antioxidant activity of most of the syrups. Awika et al (2003) reported similar results for grain sorghums. The higher correlation of TPC with ORAC than DPPH-RSA is encouraging since ORAC is based on the ability of antioxidants to protect proteins from damage by free radicals, which is more related to biological systems such as the human body. On the other hand, the DPPH methods are more simple, repeatable, and less costly than ORAC methods, which often explains why many analysts prefer it (Awika et al. 2003). In this study, the lower correlation of TPC with DPPH-RSA compared to the ORAC values may be due to one or a combination of the following: (i) experimental error of the DPPH-RSA assay, (ii) interference of syrup color with the DPPH method, (iii) other components of the syrups contributing to their DPPH-RSA values, and (iv) the presence of inihibitor/interfering compounds in the syrups.

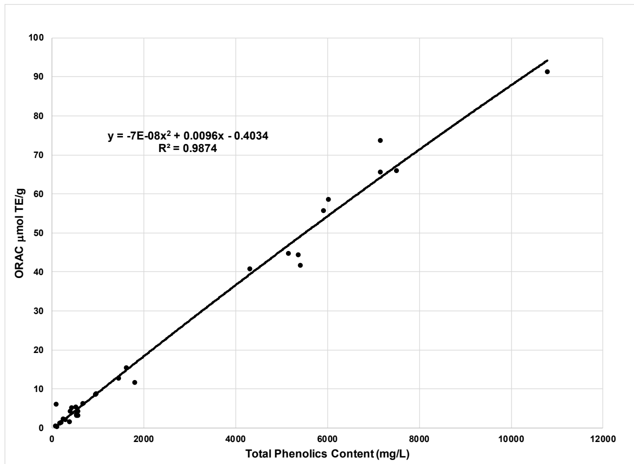


Fig. 7. Correlation between the total phenolic contents of all the syrups and ORAC antioxidant values. The correlation equation for sweet sorghum syrups only was R^2=0.946; y=1.3009x^2-58.746x+5167.

Although the color *per se* was not measured, Awika et al. (2003) observed that highly colored grain sorghums contained higher amounts of TPC and antioxidants.In this study, the colors of the syrups were measured at different pH values (4.0, 7.0, and 9.0) and wavelengths (280, 320, 420, and 510 nm) to gain information on the type of colorants present including phenolic color compounds (Fig.8). The absorption wavelength tended to have a much greater effect on color than pH, especially for sugarcane, sweet sorghum, grain sorghum, rice, and HFCS syrups (Fig. 8). It must be noted that the HFCS syrups had added caramel (process-derived) colorants added and thus the natural color of HFCS was not reflected. For this reason, HFCS syrup results are not included in the following discussions. To a marked extent, the sweet sorghum syrups exhibited the highest color values at all wavelengths (Fig. 8) which were linked to their TPC and antioxidant contents. Except for the white grain sorghum syrup, syrup colors were generally highest syrups at 280 nm and lowest at 510 nm. Flavonols have λ_{max} at 280 nm, hydroxycinnamic acid derivatives at 300-320 nm, anthocyanins at 500-520 nm (Aaby et al. 2007). The occurrence of the highest color for white grain sorghum at 320 nm is, therefore, an indication of a high content of hydroxylcinnamic acids. High levels of polyflavanols (procyanidins), anthocyanins, phenolic acids, and tannins have been reported in grain sorghum (see Awika et al. 2003).

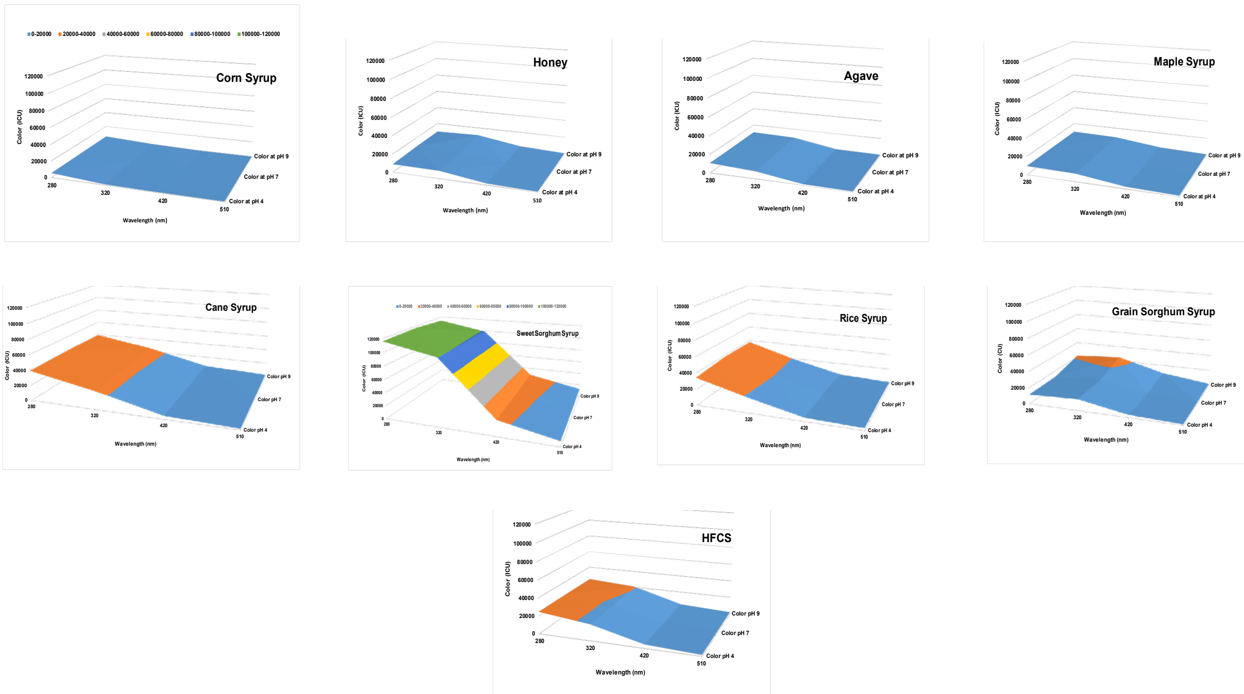


Fig. 8. Response surface graphs of color absorption, pH, and wavelength for all syrups.

Syrup Mineral Analyses

The specific minerals magnesium, iron, sodium, potassium, calcium, and phosphorus were all analyzed in the syrups using Inductively Coupled Plasma (ICP) technology, and results are illustrated in Figs.9 to 14. The five major minerals in the human body are magnesium, sodium, potassium, calcium, and phosphorus with the other elements considered "trace". In the United States, the amount of a mineral on a food label is expressed in mg per 100 g (on a fresh weight basis) of foodstuff.

Magnesium. Magnesium is an indispensable mineral required in the human diet for processing ATP (adenosine triphosphate - the source of energy transfer in human cells) and for bones. Magnesium also acts as a cofactor for hundreds of enzymes in the human body (Qureshi, 2017). Unfortunately, it is also a mineral that almost half of Americans consume in less quantities than the required daily amount. This occurs even though low magnesium levels have been associated the type-2 diabetes, metabolic syndrome, hypertension, atherosclerotic vascular disease, sudden cardiac death, osteoporosis, migraine headaches, asthma, and colon cancer (Rosanoff et al. 2011). On the other hand, with new research backing magnesium's benefits for heart and mental health, magnesium supplements have been seriously growing in the U.S.A. in recent years, with 7.9% sales growth in 2017 over 2016 (Decker and Prince, 2018). Sports nutrition is a strong area where the use of magnesium mineral supplements is growing, since magnesium plays an important role in fighting against oxidative stress and reducing inflammation and, therefore, muscle damage (Decker and Prince, 2018). Fig. 9 clearly illustrates that the sweet sorghum syrups contained dramatically ($P<0.05$) higher amounts of magnesium (mean 120 mg) than all the other syrups (mean 5 mg). Moreover, none of the other commercial syrups were good sources of dietary magnesium. The overall range of magnesium in the sweet sorghum syrups was 58 to 184 mg, with significant ($P<0.05$) differences among the various sources of sweet sorghum syrups. This variation may be due to environmental, cultivar, or processing effects. Soil nitrogen levels/nitrogen fertilizer rates can increase magnesium levels in sweet sorghum (Serrao et al. 2012) and a higher nitrogen fertilizer can promote magnesium uptake under stress salinity conditions. Currently, it is not known if magnesium in sweet sorghum varies with cultivar. During sweet sorghum processing, magnesium may be chelating with, for example, aconitic acids and then precipitating out, but further studies are needed to ascertain why magnesium varies in the commercial sweet sorghum syrups.

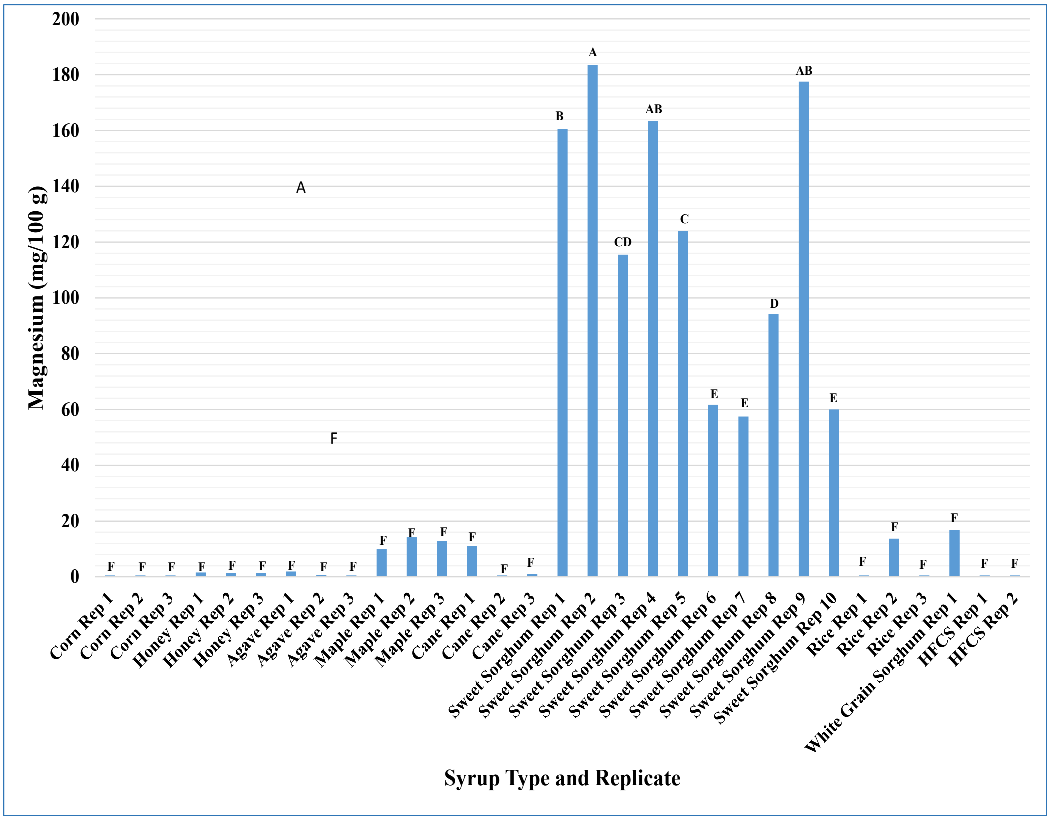


Fig.9. The mean magnesium (Mg) content of the various commercial syrups. The recommended daily allowance (RDA) for magnesium in the U.S.A. for a 19-50 year adult is 400/420 mg for a male and 310/320 mg/100 g for a female. Means followed by a different upper case letter are significantly different at the 5% probability level.

Sodium. Although sodium in the human body functions as a systematic electrolyte and is essential for co-regulating ATP with potassium, in excess sodium causes hypertension and thus the upper tolerance intake limit for sodium is limited to 2300 mg, although the recommended daily allowance (RDA) for adults in the U.S.A. is 1500 mg. The sodium contents of the syrups in this study are shown in Fig.10 and in HFCS syrups were very high (mean 245 mg). Sodium in HFCS syrups reflects the addition of both sodium chloride (salt) and sodium hexametaphosphate ingredients. Since high sodium levels are not recommended in daily diets because they cause health problems, these results indicate that HFCS has another nutritional problem than just high concentrations of fructose. Golden syrup (cane syrup rep 3; Table 1) used often in the United Kingdom, Australia, New Zealand and other countries for baking purposes, also had a relatively high sodium level (mean 407 mg) which is most likely a reflection of its production process.

Golden syrup can be made by inverting sucrose in cane syrup into the invert sugars glucose and fructose. When inverting by acid hydrolysis, the sucrose is split with hydrochloric acid resulting in an acidic solution which is then neutralized with sodium hydroxide. This results in golden syrup containing some common salt, sodium chloride (Varzakas et al. 2012). The corn syrups also contained sodium but at more moderate levels (mean 50 mg) than HFCS, and this can be attributed to salt being an added ingredient. In strong contrast, all ten sweet sorghum syrups contained (P<0.05) very low levels of sodium (1 to 22 mg) and can, therefore, be considered low sodium foods. Maple syrup and honey have previously been reported to be low- or zero-sodium food (Ball, 2007) and this was confirmed in the current study (Fig. 10).

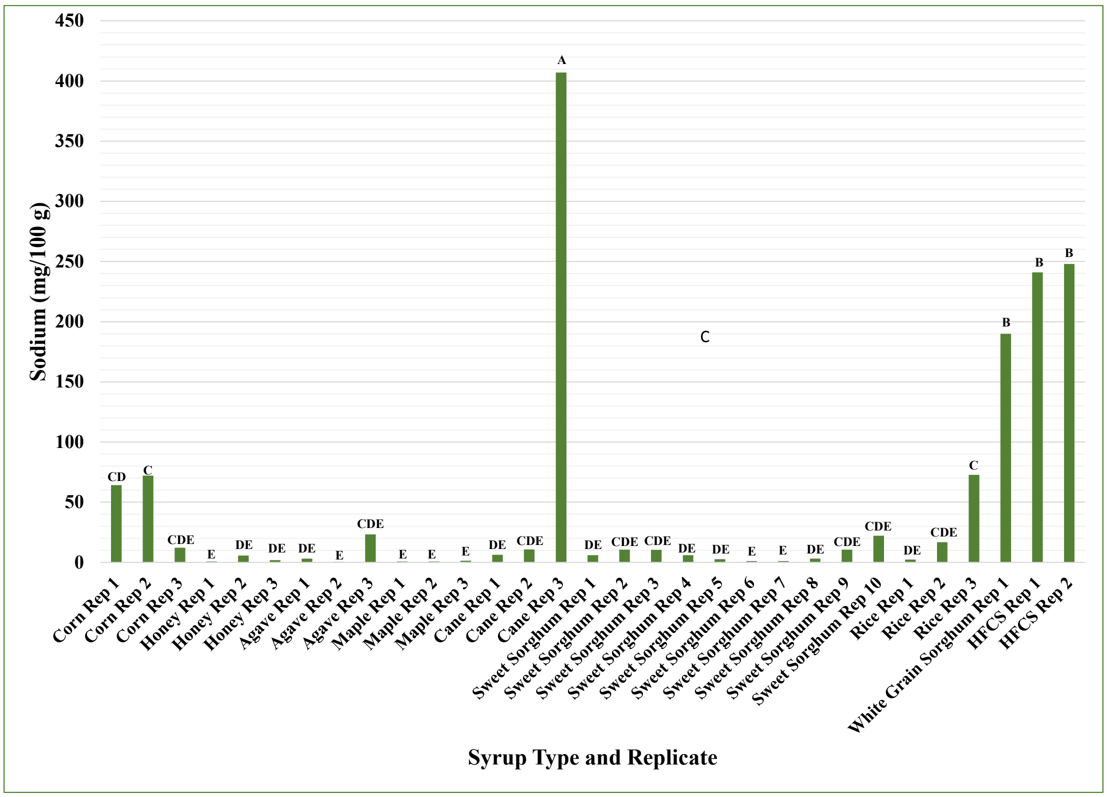


Fig.10. The mean sodium (Na) content of the various commercial syrups. The recommended daily allowance (RDA) for sodium in the U.S.A. for a 19-50 year adult is 1500 mg/100 g. Means followed by a different upper case letter are significantly different at the 5% probability level.

Potassium. Potassium is a systematic electrolyte in the human body and is essential for co-regulating ATP with sodium. Potassium is also essential for proper rehydration, to prevent muscle cramps during exercise, and is associated with lowered blood pressure (Pelofske, 2017). As shown in Fig.11, the potassium contents of all the sweet sorghum syrups were also very high (up to 1710 mg) and dramatically higher (P<0.05) than for all the other syrups. The next highest potassium levels were found in the white grain sorghum syrup (286 mg) and the maple sugars (ranged from 181 to 203 mg) which was still six-fold lower than for the sweet sorghum syrups; the rest of the syrups containing only negligible amounts. Thus overall, like for magnesium, sweet sorghum is a rich dietary source of potassium. Soil nitrogen levels/nitrogen fertilizer rates are also known to increase potassium levels in sweet sorghum although high salinity levels decrease potassium (Serrao et al. 2012).

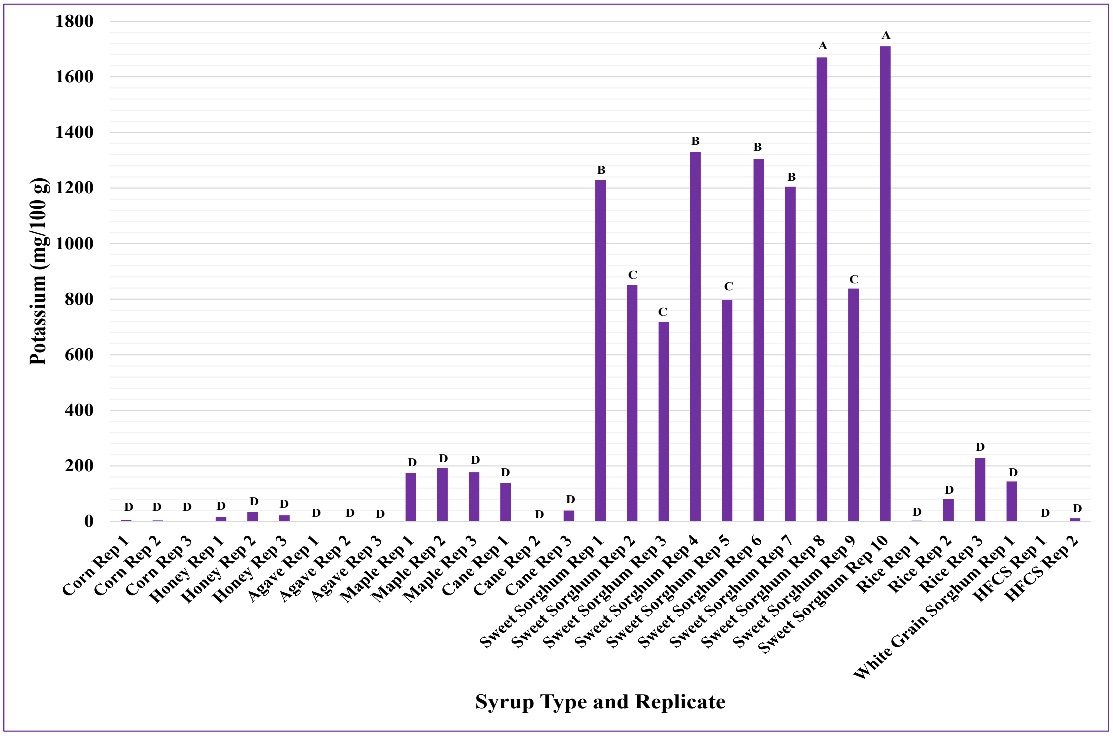


Fig.11. The meanpotassium (K) content of the various commercial syrups. The recommended daily allowance (RDA) for magnesium in the U.S.A. for a 19-50 year adult is 4700 mg/100 g.Means followed by a different upper case letter are significantly different at the 5% probability level.

Calcium. Calcium is essential in the human diet for muscle, bones, teeth, heart, and digestive system health, and it also supports the synthesis and function of blood cells. Currently, calcium is the number one selling mineral supplement in the U.S.A., mostly sold for bone health (Decker and Prince, 2018). Many foodstuffs also have to be fortified with calcium (Pelofske, 2017), but there will be no need for this with sweet sorghum products since calcium levels were high in sweet sorghum syrups, ranging from 112 – 468 mg (Fig.12). HFCS and corn syrups only contained <2 mg and, therefore, are not good sources of dietary calcium. Calcium values in the three maple syrup brands varied ($P<0.05$) from 74 – 98 mg, but were still less than half the values for the sweet sorghum syrups (Fig.12). There are numerous reasons why calcium levels varied in the ten sweet sorghum syrups. The brand T sweet sorghum syrups (reps 6 to 8) contained the highest calcium levels because lime (milk of lime) is added during the clarification process. Calcium is also known to chelate with aconitic acids during sweet sorghum processing which then precipitating out. Soil nitrogen levels/nitrogen fertilizer rates can increase calcium levels in sweet sorghum (Serrao et al. 2012) and calcium may also vary with cultivar. Further studies are needed to ascertain why calcium varies in the commercial sweet sorghum syrups.

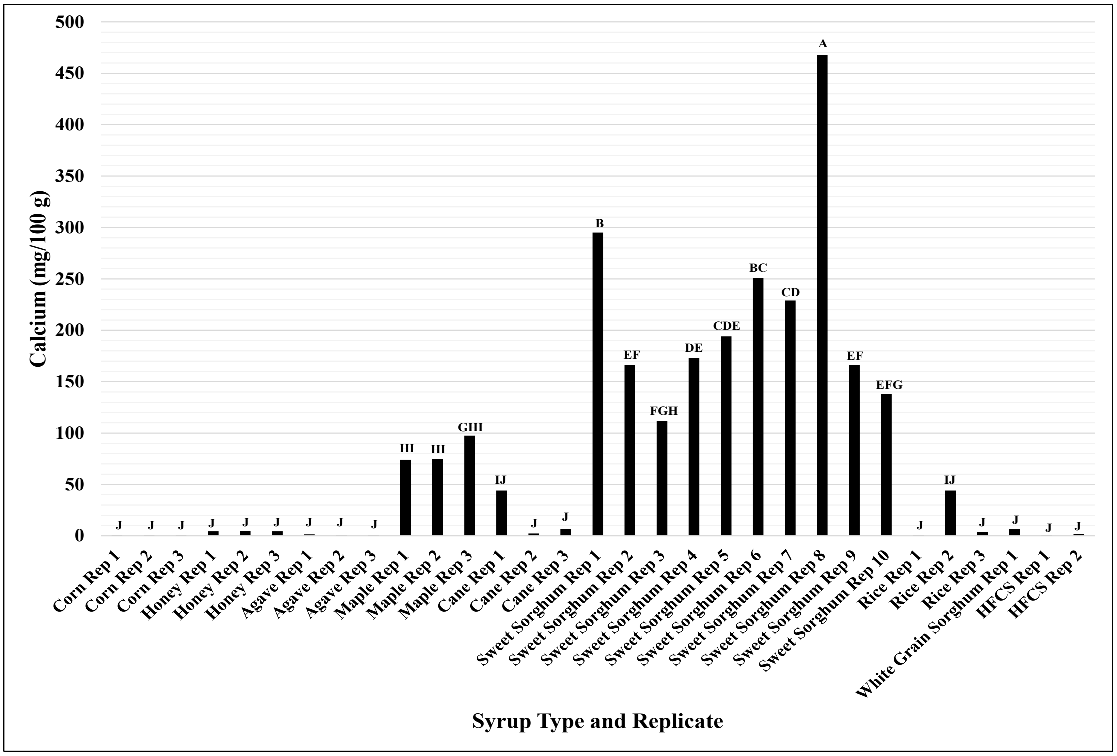


Fig.12. The mean calcium (Ca) content of the various commercial syrups. The recommended daily allowance (RDA) for magnesium in the U.S.A. is 1000 mg/100 g. Means followed by a different upper case letter are significantly different at the 5% probability level.

Phosphorus. Phosphorus is a multi-functional ingredient which is (i) an essential component of bones and cells, (ii) important for energy processing in the human body, and (iii) an important component of ATP and DNA. Phosphates are the most common naturally occurring form of phosphorus, and regarded as a multi-functional ingredient (Pelofske, 2017).The phosphorus contents of the commercial syrups are illustrated in Fig.13. Corn syrup, honey, agave, maple, and cane syrups contained negligible amounts of phosphorus which were not significantly different at the 5% probability level (Fig.13). The highest amount of phosphorus (203 mg) occurred ($P<0.05$) in white grain sorghum syrup. The two HFCS brands contained a slight amount of phosphorus (mean 25 mg/100 g) which can be attributed to the addition of sodium hexametaphosphate (phosphate food additive) (Table 1). All the sweet sorghum syrups contained phosphorus but these varied considerably from 9 to 149 mg (mean 56 mg). Serrao et al. (2012) reported that soil nitrogen levels/nitrogen fertilizer rates consistently increased phosphorus levels in sweet sorghum. The lower values of brand T sweet sorghum syrups are most likely due to chelation with calcium during floc formation in juice clarification. As stated earlier in this report, juice clarification is important during sweet sorghum processing to remove interfering starch granules. Other variations may be due to cultivar or processing effects.

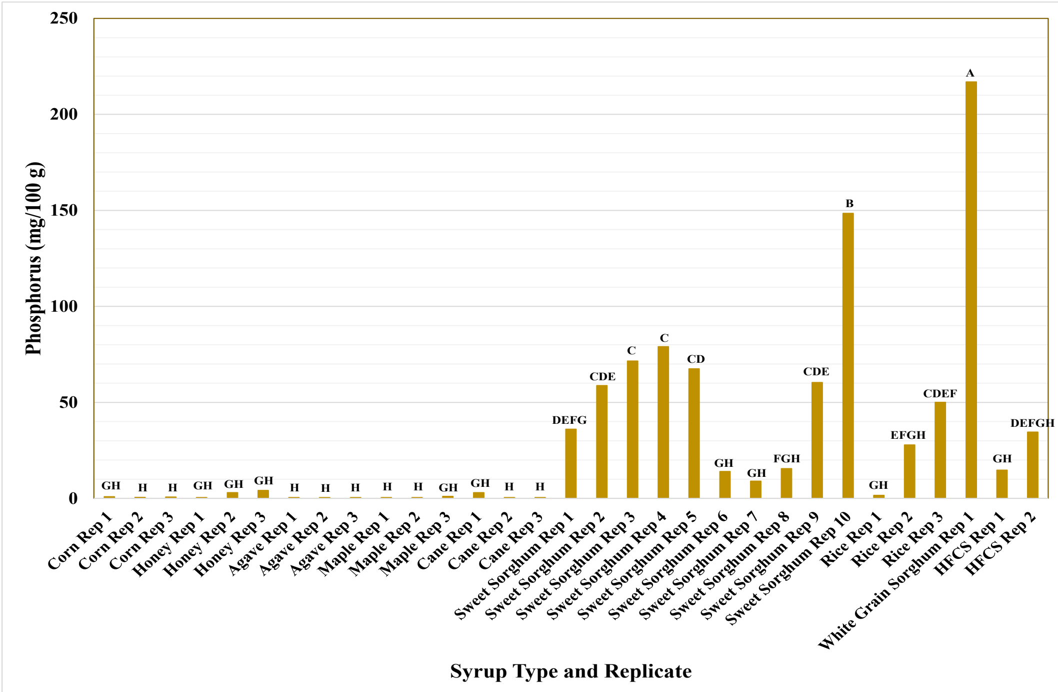


Fig.13. The meanphosphorus (P) content of the various commercial syrups. The recommended daily allowance (RDA) for phosphorus in the U.S.A. for a 19-50 year adult is 700 mg/100 g. Means followed by a different upper case letter are significantly different at the 5% probability level.

Iron. The contents of the trace mineral iron in the commercials syrups are also illustrated in Fig.14, which clearly illustrates that only sweet sorghum syrups were a viable source of iron (mean 17 mg) compared to the other syrups which contained only negligible amounts (<0.5 mg). Iron is needed in human diets for the functioning of many proteins and enzymes, notably hemoglobin in the blood to prevent anemia. Iron varied ($P<0.05$) in the sweet sorghum syrups ranging from 2 to 73 mg. Like for magnesium, this variation in iron may be due to cultivar or processing effects. Additionally, since many manufacturers utilize iron (usually mild steel) tanks to produce sweet sorghum syrup this could have been a source of the iron but, again, studies are needed to evaluate this.

Overall, the individual mineral results reported herein underpin and explain the total ash results in Table 3, with no surprise that the sweet sorghum syrups contained markedly more total ash considering the much higher amounts of many minerals shown in Figs.9 to 14.

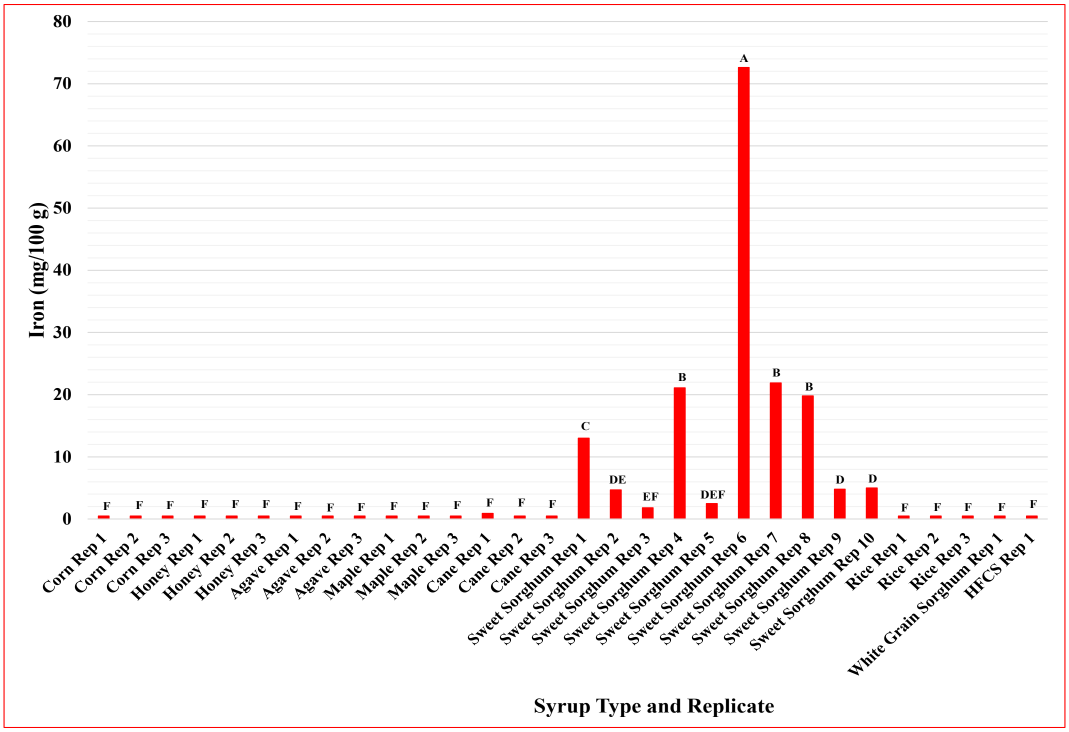


Fig.14. The meaniron (Fe) content of the various commercial syrups. The recommended daily allowance (RDA) for iron in the U.S.A. for a 19-50 year adult is 8 mg for a female and 18 mg/100 g for a male. Means followed by a different upper case letter are significantly different at the 5% probability level.

Dietary Amounts of Sweet Sorghum Nutrients Per Daily Allowance.

The average dietary amount for the nutrients per serving in the various syrups in this study are listed in Table 5. The per cent daily values (DV) are also listed in Table 5. DVs are set by the Food and Drug Administration (FDA) of the United States government to help consumers compare the nutrient contents of products within the context of a total diet. The DV is the amount or percentage of a nutrient that is provided by a single serving. For syrups in this study the single serving was 1/8 cup or 2 tbsps or 30 mL. For nutrients with a recommended dietary allowance (RDA) for a 2000 Calorie/day diet (most healthy adults fit into this range) the DV was calculated based on this, otherwise the DV was calculated from the RDA's upper limit.

Except for HFCS which had a markedly ($P<0.05$) lower Brix value (Table 2) than the other syrups, the Calorie values for the syrups did not vary widely and contributed 6.7 to 8.8% DV (Table 5). The Calorie values were highly (linearly) dependent on Brix (R^2=0.973), density (R^2=0.980), and carbohydrate (R^2=0.991) amounts. The syrups contributed only small amounts of fat and protein to the daily values with agave contributing the highest fat DV of 3.2% and sweet sorghum syrup the highest protein DV of 1.5% (Table 5). Except for sweet sorghum syrup, which with one serving (49.3 mg) contributed enough magnesium for nearly one quarter (DV 23.4%) of the daily diet need, the other syrups contributed negligible amounts of magnesium. Almonds are high in magnesium at 32 to 281 mg per 100 g. Although most syrups contained low DV values for sodium, HFCS still contained a DV of 5.7%. Sweet sorghum contained dramatically higher potassium and calcium amounts than all the other syrups at 10.2 and 9.0% DV values, respectively, per serving. Bananas are often recommended as rich sources of potassium, but a medium size banana (one serving of 100 g) contains 358 mg or 8%DV (Anon, 2018), which is lower than per serving of sweet sorghum syrup (Table 5). Phosphorus was highest in sweet sorghum and particularly grain sorghum with the latter containing 12.9% per serving. Iron was negligible in servings of the syrups except for sweet sorghum that contained over half (52.7%) of the daily value for this mineral, which indicates it may even be able replace iron supplements.

Table 5. Dietary Amounts of Sweet Sorghum Nutrients Per Serving (Nutrition Facts). Results are Based on Mean Values for all the Syrup Replicates.

Commercial Syrup:	**Corn**		**Honey**		**Agave**		**Maple**		**Cane**		**Sweet Sorghum**		**Rice**		**White Grain Sorghum**		**HFCS**	
	Amount Per Serving (Serving Size 1/8 cup or 2 tbsp(30 mL)[a]																	
		% DV[b]		**% DV**		**% DV**		**% DV**		**% DV**		**% DV**		**% DV**		**% DV**		**% DV**
Calories	161.9 Cal	**8.1**	175.8 Cal	**8.8**	166.8 Cal	**8.4**	133.7 Cal	**6.7**	158.4 Cal	**7.9**	153.4 Cal	**7.7**	168.4 Cal	**8.4**	162.2 Cal	**8.1**	82.8 Cal	**4.2**
Total Fat	0.06 g	**0.2**	0.16 g	**0.6**	0.87 g	**3.2**	0.27 g	**1.0**	0.36 g	**1.3**	0.34 g	**1.3**	0.36 g	**1.3**	0.04 g	**0.2**	0.09 g	**0.4**
Total Protein	0.21 g	**0.4**	0.30 g	**0.6**	0.11 g	**0.2**	0.14 g	**0.3**	0.19 g	**0.4**	0.75 g	**1.5**	0.42 g	**0.8**	0.58 g	**1.2**	0.11 g	**0.2**
Total Carbohydrate	33.2 g	**25.5**	36.6 g	**28.1**	32.5 g	**25.0**	25.8 g	**19.8**	31.4 g	**24.2**	30.1 g	**23.1**	33.6 g	**25.9**	32.9 g	**25.3**	14.2 g	**10.9**
Magnesium[c]	0.21 mg	**<0.1**	0.62 mg	**0.17**	0.42 mg	**0.1**	4.87 mg	**1.3**	1.72 mg	**0.5**	49.3 mg	**23.4**	2.03 mg	**0.6**	7.0 mg	**1.9**	0.18 mg	**0.05**
Sodium	20.5 mg	**1.4**	1.14 mg	**<0.1**	3.73 mg	**0.3**	0.39 mg	**<0.1**	57.7 mg	**3.9**	3.04 mg	**0.2**	12.7 mg	**0.85**	78.7 mg	**5.3**	86.0 mg	**5.7**
Potassium	1.66 mg	**<0.1**	10.6 mg	**0.2**	0.22 mg	**<0.1**	71.8 mg	**1.53**	24.4 mg	**0.5**	479.0 mg	**10.2**	43.2 mg	**0.92**	59.6 mg	**1.3**	21.8 mg	**0.5**
Calcium	0.22 mg	**<0.1**	1.92 mg	**0.2**	0.33 mg	**<0.1**	32.5 mg	**3.3**	7.3 mg	**0.7**	90.1 mg	**9.0**	6.7 mg	**0.67**	2.82 mg	**0.3**	0.42 mg	**<0.1**
Phosphorus	0.30 mg	**<0.1**	1.43 mg	**0.2**	0.21 mg	**<0.1**	0.28 mg	**<0.1**	**<0.1**	**<0.1**	23.1 mg	**2.3**	11.0 mg	**1.6**	89.9 mg	**12.9**	8.65 mg	**1.3**
Iron[d]	0.20 mg	**1.6**	0.21 mg	**1.6**	0.21 mg	**1.6**	0.20 mg	**1.6**	0.26 mg	**2.0**	6.85 mg	**52.7**	0.21 mg	**1.6**	0.21 mg	**1.6**	0.18 mg	**1.4**

[a] Amount per serving weight in grams was calculated using the mean density of each syrup type with corn, honey, agave, maple, cane, sweet sorghum, rice, grain sorghum, and HFCS having mean densities of 1.38, 1.410, 1.38, 1.32, 1.36, 1.37, 1.38, 1.38, and 1.17 g/mL, respectively.

[b]Daily value results for calories are based on a 2000 Cal day diet for an adult. Daily Value results for total fat, total protein, and total carbohydrate were based on average RDA for an adult of 27.5 g/day (20 to 25 g/day range), 51 g/day (male 56 g/day and female 46 g/day), and 130 g/day, respectively. Unless otherwise stated below the % daily value of each mineral nutrient is based on the average RDA for an adult stated in Figure 3 to 8 captions

[c]% Daily Value for magnesium is based on an average 370 mg RDA for an adult

[d]% Daily Value for iron is based on an average 13 mg RDA for an adult

Sensory Flavor

The descriptive flavor panel developed terms and definitions for syrups. The final list of terms consisted of seventeen flavors, seven feeling factors, and four tastes. In addition, the panelists generated terms and definitions for eighteen flavors and three feeling factors that are seldom observed, but may be present in an occasional syrup. These are included at the end of the descriptor lexicon (Table 6). To prevent fatigue of panelists, some similar terms were combined on the ballot. For example, vanilla, maple, and honey were combined to make honey/vanilla/maple. When a panelist observed one or more of these flavors they noted the intensity under the combined term.

Table 6. General Syrup flavor lexicon with definitions.

Fruity

Raisin-a browned, sweet, fruity aromatic, reminiscent of dried raisins.

Prune- a browned, sweet, fruity aromatic, reminiscent of dried prunes.

Dried fruit (peach/apricot)-the fermented, sweet, fruity aromatic, reminiscent of dried peaches or apricots.

Cooked apple-aroma associated with cooked apples/apple sauce.

Sweet Aroma

Honey-sweet, caramelized, floral, and woody aroma associated with honey.

Vanilla-blend of sweet, vanillin, woody, browned notes associated with vanilla bean.

Maple-sweet aroma with a blend of caramelized, woody, vanilla-like notes associated with maple syrup.

Caramel-general term associated with chewy caramel or toffee.

Butterscotch-sweet aroma typically having both caramelized and buttery notes.

Root beer/sassafras-aroma associated with root beer flavoring or sassafras.

Molasses/cane syrup-aroma associated with molasses, with a sharp, slight Sulphur and/or caramelized character.

Brown sugar-a rich, full-bodied, brown, sweet aroma.

Anise/black licorice-sweet, spicy, licorice-like aroma

Herbaceous

Sweet potato-aroma associated with baked sweet potato

Hay/Straw-aroma associated with sweet, dry, grasses to slightly dusty, dry grain stems

Cereal

Malt-sweet, slightly fermented note associated with malt powder.

Short Bread-baked aroma of short bread cookies.

Chicory/coffee-aroma associated with fresh ground coffee or ground chicory.

Woody/Nutty

Pine/resinous/pencil shaving-aroma associated with tree sap, fresh-cut pine, or pencil shavings.

Oak/woody-dry woody aroma associated with oak barrels, or old wood furniture.

Burnt/charred wood-aroma associated with burnt carbohydrates such as, sugar, wood, or matches.

Lipid

Bee's wax/waxy/paraffin-aroma associated with unscented candle wax, crayons, and bee's wax.

Cardboard-aroma reminiscent of wet brown paper, wet cardboard box, or corrugated cardboard.

Dairy

Buttery-aroma associated with un-salted butter.

Chemical

Medicinal/pharmacy-aroma/flavor associated with not cherry, citrus, or grape flavored cough syrup, phenol, iodine, thymol, iso-propyl alcohol, etc.

Plastic-aroma associated with plastic polyethylene containers, plastic packaging, or plastic toys.

Other

Earthy/musty/potato peel-aroma associated with dry earth, wet earth, or the peel from fresh potatoes.

Sour aroma-a sharp aroma associated with fermented products, or acidic products.

Mouth feeling factor

Astringent-the chemical feeling factor on the tongue described as puckering/drying and associated with tannins or alum.

Warming-the chemical feeling factor that produces a warming sensation in the mouth.

Cooling-the chemical feeling factor that produces a cooling sensation in the mouth.

Tongue tingle-a feeling of increased sensation on the tongue that may be due to carbonation or other causes. Evaluate during the first 3-5 seconds after sample is placed in mouth.

Prickly/Bite-the prickly feeling associated with club soda touching the tongue.

Tongue numbing-loss of sensation on tongue evaluated after swallowing the sample.

Throat burn/sting-the chemical feeling factor described as a burning sensation perceived in the throat or on the back of the tongue.

Oily mouth feel-the feeling factor on the mouth parts that feels like oil coating.

Taste

Sweet-basic sweet taste associated with sugar

Sour- basic sour taste associated with acid or acidic foods.

Salty-basic salty taste associated with sodium-chloride.

Bitter-basic bitter taste associated with caffeine, quinine

Other Flavors and feeling factors

Citrus (fresh)-aroma associated with general impression of citrus fruits

Citrus (peel)-aroma associated with general impression of citrus zest.

Other fruit-general fruity aroma, not citrus.

Blossom-aroma associated with jasmine, orange, or satsuma blossom

Other floral-floral aroma associated with rose, or other specified flower.

Brown spice-general aroma associated with cloves, cinnamon, and nutmeg

Sweet aroma-generally sweet aroma

Cotton candy-aroma associated with cotton candy.

Green/grassy-slightly sweet aroma associated with fresh cut grass

Silage/fermented-aroma associated with brown sugary fermented cut hay or fermented cattle feed.

Vegetable-like-aroma associated with leafy green vegetables.

Herb-like-aroma typical of dried herbs such as, cumin, thyme, rosemary.

Starchy-aroma associated with heated starch in water.

Grainy-general term associated with raw grains

Toasted/bread crust-aroma associated with bread crust or toasted bread.

Cracker -cooked wheat aroma associated with unsalted soda cracker.

Nutty/almond-aroma associated with nut meats and nuts like almonds.

Oxidized/rancid-aroma characteristic of oxidized foods or rancid oil (could be described as paint, tallow, or cardboard).

Cheese-aroma associated with fresh Colby cheese or processed powdered cheese.

Sulfur-aroma associated with stuck match or boiled egg.

Solvent-aroma associated with chemical solvents such as, acetone, alcohols, mineral spirits, or plasticizers.

Moldy-aroma characteristic of mold growth or mildew.

Animal (leather/sweat/urine/barnyard/cowshed/stable)-general aroma associated with live animal including sweat, urine, bedding, or leather aroma.

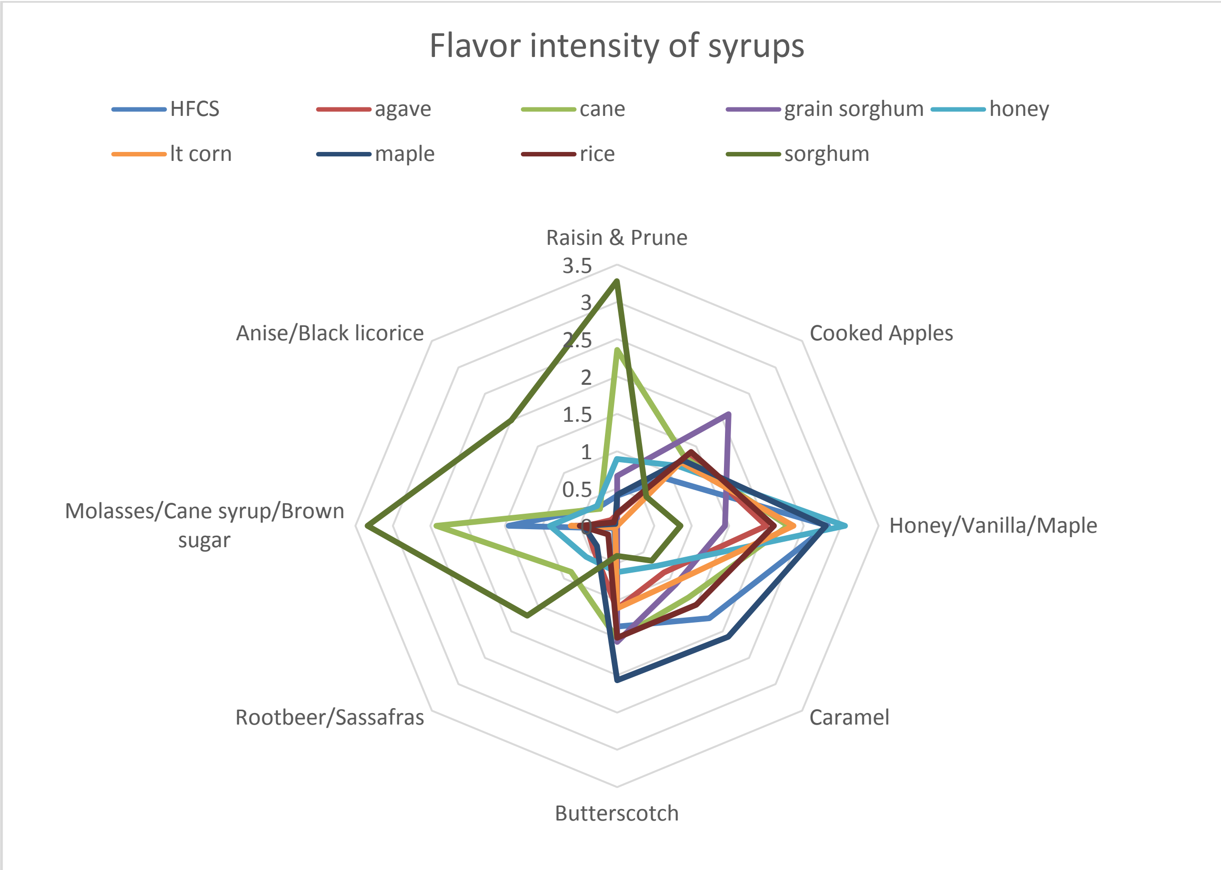
Metallic-chemical feeling factor on the tongue stimulated by metal ions such as ferrous sulfate.

Hot/heat/peppery-chemical feeling factor from burning compounds in foods as capsicum, red pepper, or radish.

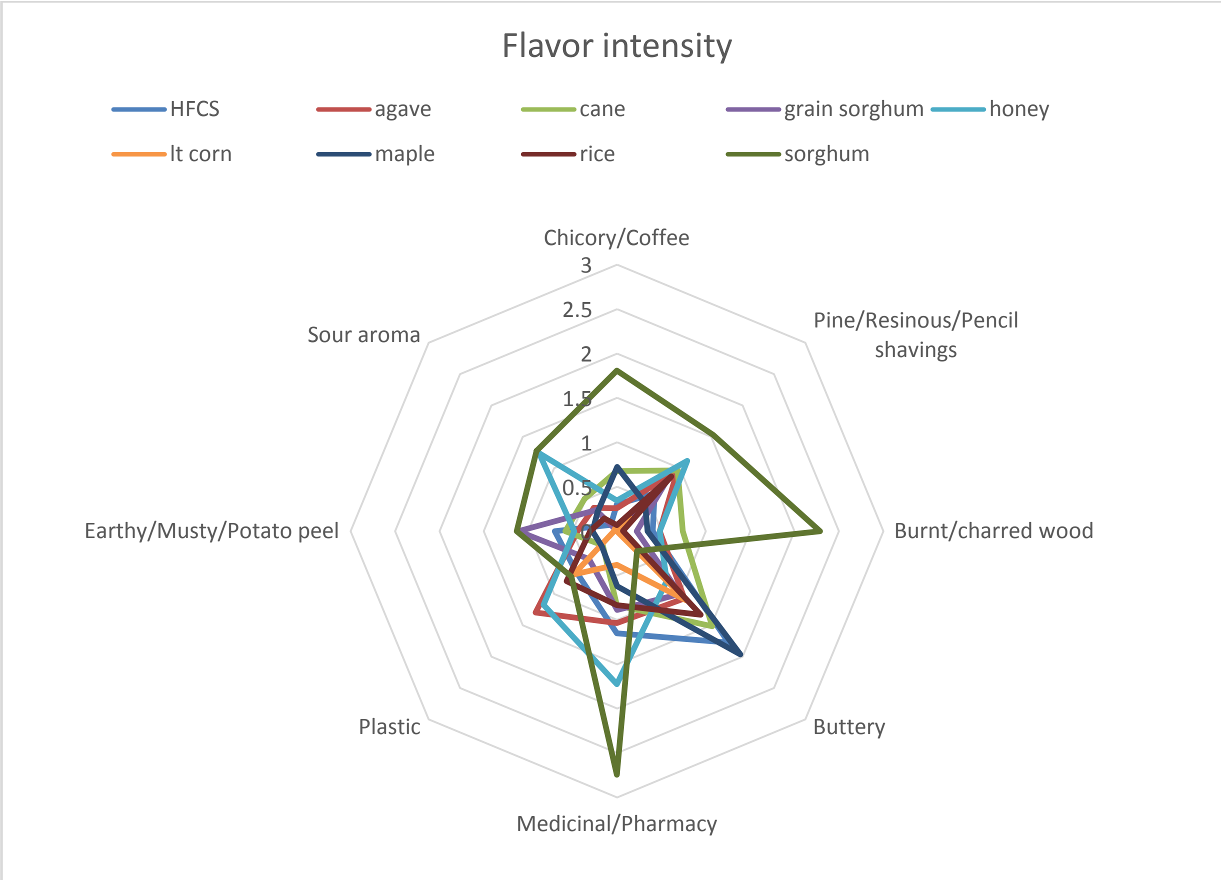
Means of selected flavor descriptors are shown in Fig. 15a, b, and c. Sweet sorghum syrup had greater intensities for raisin & prune, root beer/sassafras, molasses/cane syrup/brown sugar, and anise/black licorice flavors than the other types of syrups (Fig. 15a). In Fig. 15b, sweet sorghum syrup had greater intensities for chicory/coffee, pine/resinous/pencil shavings, burnt/charred wood, and medicinal/pharmacy. In Fig 15c, sweet sorghum syrup was more intense in astringent, sour taste, and bitter taste. Even though it was greater in fructose, it was not as sweet as the other syrups because of the sour and bitter tastes that modulated the sweet taste. This work displays the unique flavor properties of each syrup type.

Figure 15. Flavor intensity comparison of syrup types for key flavors, feeling factors, and tastes.

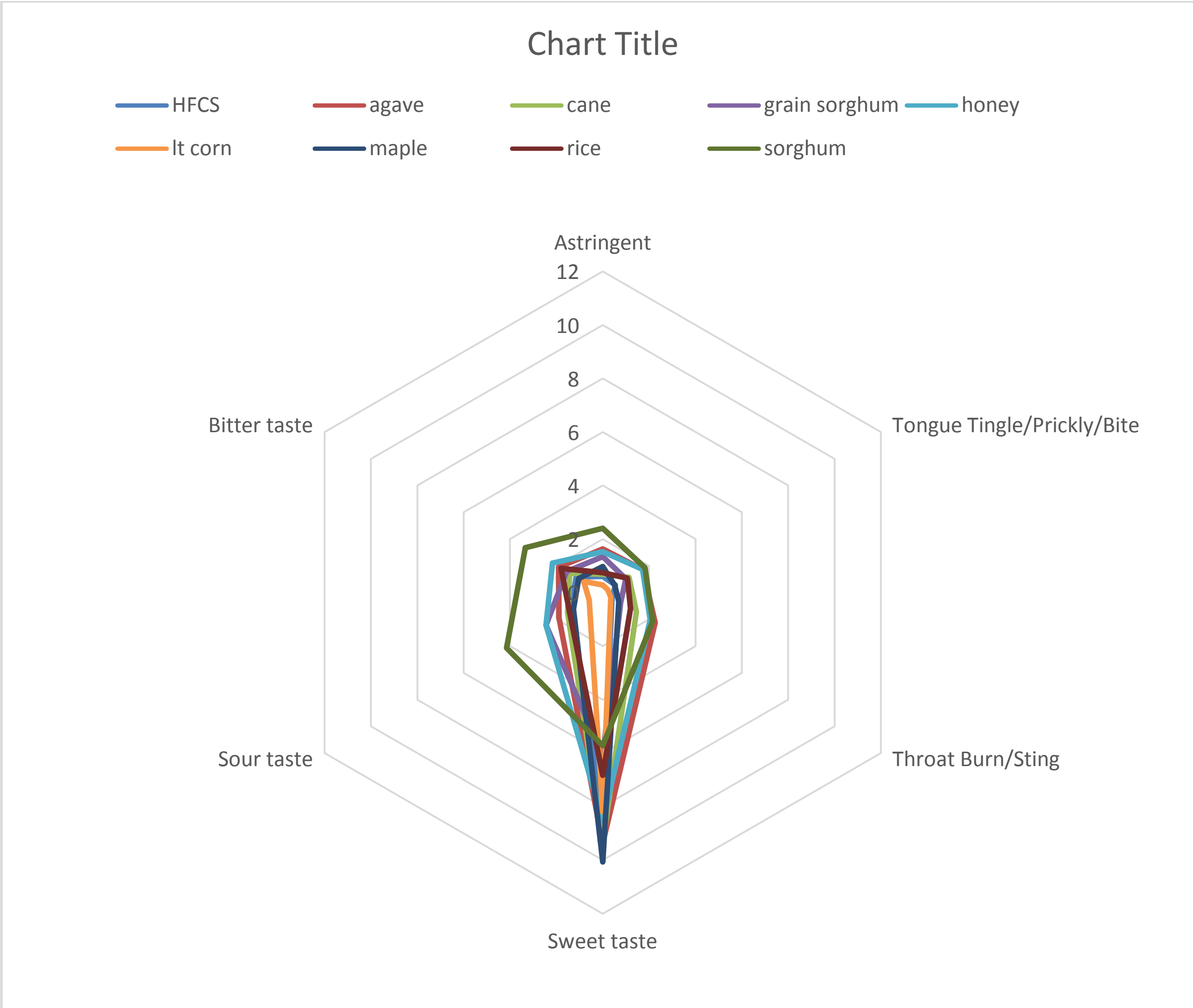
a) Fruity, sweet aromatic, cereal, and herbaceous flavors



b) Other flavors



c) Feeling factors and tastes



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